

Taxonomic guide and historical review of starfishes in northeastern Brazil (Echinodermata, Asteroidea)

Anne Isabelley Gondim¹, Martin Lindsey Christoffersen¹,
Thelma Lúcia Pereira Dias²

1 Universidade Federal da Paraíba, Programa de Pós-Graduação em Ciências Biológicas (Zoologia), Departamento de Sistemática e Ecologia, Laboratório de Invertebrados Marinhos Paulo Young, Bairro Cidade Universitária s/n, CEP. 58059-900, João Pessoa, PB, Brasil **2** Universidade Estadual da Paraíba, CCBS, Departamento de Biologia, Laboratório de Biologia Marinha, Campus I, Rua Baraúnas, 351, Bairro Universitário, CEP 58429-500, Campina Grande, PB, Brasil

Corresponding author: Anne Isabelley Gondim (anneisabelley@yahoo.com.br)

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Abstract

Presently more than 1900 species of sea stars are recognized, of which 77 are recorded for the coast of Brazil. Although the first starfish record in Brazil was published 363 years ago, our knowledge of this fauna remains unsatisfactory from a systematic and ecological point of view, particularly in the north and northeastern regions of the country. This study provides the first annotated list of sea stars from northeastern Brazil. Material described herein is housed at the collections of the Federal University of Paraíba, Federal University of Sergipe, and the Federal University of Bahia, Museum of Zoology of the University of São Paulo and Museu Nacional do Rio de Janeiro. Twenty-one species were identified, belonging to 12 genera, 10 families, and 5 orders. Descriptions of species are provided. Three new occurrences were recorded for northeast Brazil: *Astropecten alligator*, *Luidia ludwigi scotti*, and *Mithrodia clavigera*. Highest diversities of Asteroidea were encountered for the states of Bahia (n = 14 spp), Paraíba (n = 12 spp) and Pernambuco (n = 9 spp). No species were recorded for the states of Maranhão and Sergipe. Sandy substrates and depths below 10 m were the least sampled areas over the continental shelf. Herein we provide a first panorama on the fauna of Asteroidea occurring in the northeast region of Brazil, hopefully to function as a basic reference for biodiversity studies in this poorly studied area.

Keywords

Echinoderms, taxonomy, check list, sea-stars, northeastern Brazil

Introduction

The Asteroidea represent the second most diverse group within the phylum Echinodermata, with an estimated number of 1900 living species (Mah and Blake 2012). Of these, 77 species are recorded for the Brazilian coastline (Ventura et al. 2012).

The first paper to deal with the Echinodermata of the Brazilian littoral was published by Georg Marcgraf (1648) and entitled “Natural History of Brazil”. In this work, animals observed from an expedition to northeast Brazil during the stay of the Count of Nassau are described, sometimes in a rather fanciful way (Hadel et al. 1999). Among the diverse groups described and illustrated by Marcgraf are two species of starfish (*Luidia senegalensis* as *Stella senegalensis*, and *Oreaster reticulatus*). Later C. F. Hartt collected 16 species of echinoderms from Abrolhos (Bahia), of which four were asteroids (*Oreaster reticulatus*, *Linckia guildingi*, *Echinaster (Othilia) echinophorus*, and *Coscinasterias tenuispina*) (Verrill 1868). Between 1875 and 1877 this same author collected another 62 species of echinoderms, which were described by Rathbun (1879). That paper furnished the first list of echinoderms from Brazil and in it 12 species of asteroids were recorded.

Thirty six years after the paper by Rathbun (1879), Verrill (1915) published a new list with descriptions and illustrations of 125 species of sea-stars from the West Indies, Florida, and Brazil. Later H. P. Oliveira (1940) furnished a new list of the Brazilian asteroids. Since then, several contributions on the marine benthic fauna were published by diverse authors, which increased our knowledge of the Brazilian asteroids. Concomitantly, several papers were published on the Echinodermata from Brazil by Dr. Luiz Roberto Tommasi. The paper published by Tommasi (1970) is his main contribution to the Class Asteroidea. In this work he produced descriptions and illustrations of the 42 species then known for the coast of Brazil.

After these pioneer studies, several works focusing on taxonomy, ecology and geographical distribution were developed, mainly in the south and southeast (e.g. Brito 1960, Carrera-Rodríguez and Tommasi 1977, Monteiro and Pardo 1991, Ventura and Fernandes 1995, Ventura et al. 1997, Nobre and Campos-Creasey 2000, Alves et al. 2002, Carvalho and Ventura 2002, Gibran 2002, Calil et al. 2009, Mariante et al. 2010).

For northeast Brazil, only three papers have focused on the Asteroidea: Lima-Verde and Matthews (1969), who studies the feeding habits of *Luidia senegalensis* in the State of Ceará; Manso (2006), who recorded the first Goniasteridae for the Potiguar Basin in the Cretaceous of Brazil, and Matthews and Lima-Verde (1969), who furnished ecological information on *Oreaster reticulatus* from the northeastern region. Knowledge on diversity along the northeastern littoral stems from species inventories. Among these: Lima-Verde (1969) recorded seven species along Ceará, Rio Grande do Norte, Pernambuco and Alagoas; Tommasi (1970) recorded six species for several northeastern states; Tommasi and Aron (1988) expanded to ten the known species from Bahia; Fernandes et al. (2002) record six species from Pernambuco; Magalhães et al. (2005) cited eight species for Bahia; Gondim et al. (2008) recorded five species for Paraíba; Gondim and Giacometti (2010) and Gondim et al. (2013) signaled two species for the coast of Piauí; and Miranda et al. (2012) recorded eight species from Alagoas.

Northeastern Brazil has a coastline with 3,400 km in extension (Pinheiro et al. 2008), which represents 42.5% of the entire Brazilian coastline. This region contains a great variety of ecosystems and has one of the largest reef environments of the South-western Atlantic Ocean. Notwithstanding, many areas remain unexplored (Marques and Lamas 2006) and our knowledge of the macrozoobenthos below 20 m is still limited, mainly regarding the outer platform and the continental slope (Migotto and Tiago 1999). Brazil has organized few marine expeditions (an example being the Programa de Avaliação do Potencial Sustentável de Recursos Vivos na Zona Econômica Exclusiva - REVIZEE), but most results continue concentrated in the south and southeastern regions, the addition of information for the north and northeastern regions being minimal below 20 m depth (Marques and Lamas 2006).

Although the first record of the Asteroidea for the Brazilian littoral was made about 363 years ago, the knowledge of this fauna in the north and northeastern regions still remains unsatisfactory and punctual, from both a systematic and an ecological point of view. The aim of the present work is to expand our knowledge on the morphology of the species of Asteroidea from northeastern Brazil.

Materials and methods

Species determinations were based mainly on Tommasi (1970), Clark and Downey (1992), and Hendler et al. (1995). Synonyms were compiled from Tommasi (1970), Clark and Downey (1992), and Mah (2013). We provide a reference to the first work mentioning the synonym and to the main papers on the Brazilian fauna that subsequently cite the species.

Illustrations are based on photos made with a Canon A640 10MP camera coupled with a Nikon stereomicroscope. Morphometrics were recorded with a digital EDC 6 caliper ruler.

The studied material is conserved in 70% alcohol or preserved dry and registered in the visited collections.

Study area

The littoral region of northeast Brazil extends for approximately 3,400 km (Pinheiro et al. 2008), beginning in the Parnaíba River Delta and extending first to the east and then to the south up to the border of between the States of Bahia and Espírito Santo. The region encompasses nine coastal States: Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, and Bahia (Fig. 1).

The region has a great diversity of littoral environments, such as beaches, dunes, cliffs, estuaries, deltas, sandbanks, reefs and underwater biotopes, such as rhodolith beds, seagrass beds and coral habitats (Fig. 2). They share Tertiary sediments from the Barreiras Formation, beach rocks, and coral reefs (Suguio 2003). This coastal diversity, allied to

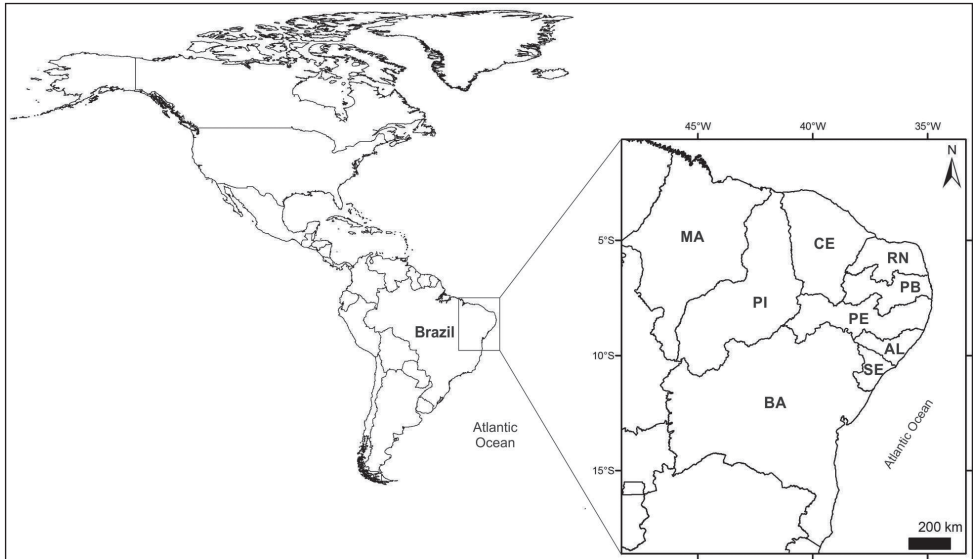


Figure 1. Map of the Americas showing the northeast region of Brazil divided in the nine states. **MA** Maranhão **PI** Piauí **CE** Ceará **RN** Rio Grande do Norte **PB** Paraíba **PE** Pernambuco **AL** Alagoas **SE** Sergipe, and **BA** Bahia.

the favorable climatic conditions and year-round warm waters, makes this region one of the most important tourist destinations in the country (Pinheiro et al. 2008).

Due to the absence of large rivers and to the predominance of warm waters from the South Equatorial Current, offshore conditions in the northeast region are ideal for the formation of coastal coral reefs (Maury 2002). The most common formations along the coast are arenitic beach rocks (Mabesoone and Coutinho 1970), which harbour scleractinian corals and calcareous algae. Reefs composed exclusively of calcareous algae and corals also occur commonly. At the South of the State of Bahia, singular mushroom-shaped coral-reef formations, denominated locally as “chapeirões”, are present offshore (Abrolhos region).

The northeastern continental shelf is narrow and shallow. Due to the reduced continental influence and to the tropical climate, an important sedimentation of biogenic carbonates dominates most of the middle and outer platform, particularly between Macau (RN) and Maceió (AL) (Coutinho 2006). The platform ends very abruptly around depths of 60–80 m. The isobath of 20 m coincides mostly with the extent of the platform. The continental shelf may reach an extent of 60 miles at Cape São Roque (RN), and less than 5 miles in front of Recife (PE) (Kempf et al. 1970).

The biogenic carbonates form sand and gravel, consisting mainly of incrusting and ramified calcareous algae, with local occurrences of *Halimeda* spp. These sediments may contain up to 5% of carbonatic mud derived from the desintegration of larger organisms. In certain areas, these sediments undergo a process of litification, also affecting the quartzose sands of the inner platform, originating the extensive coastal reefs known as beach rocks. These then become overgrown by algae and corals (Lana et al. 1996).

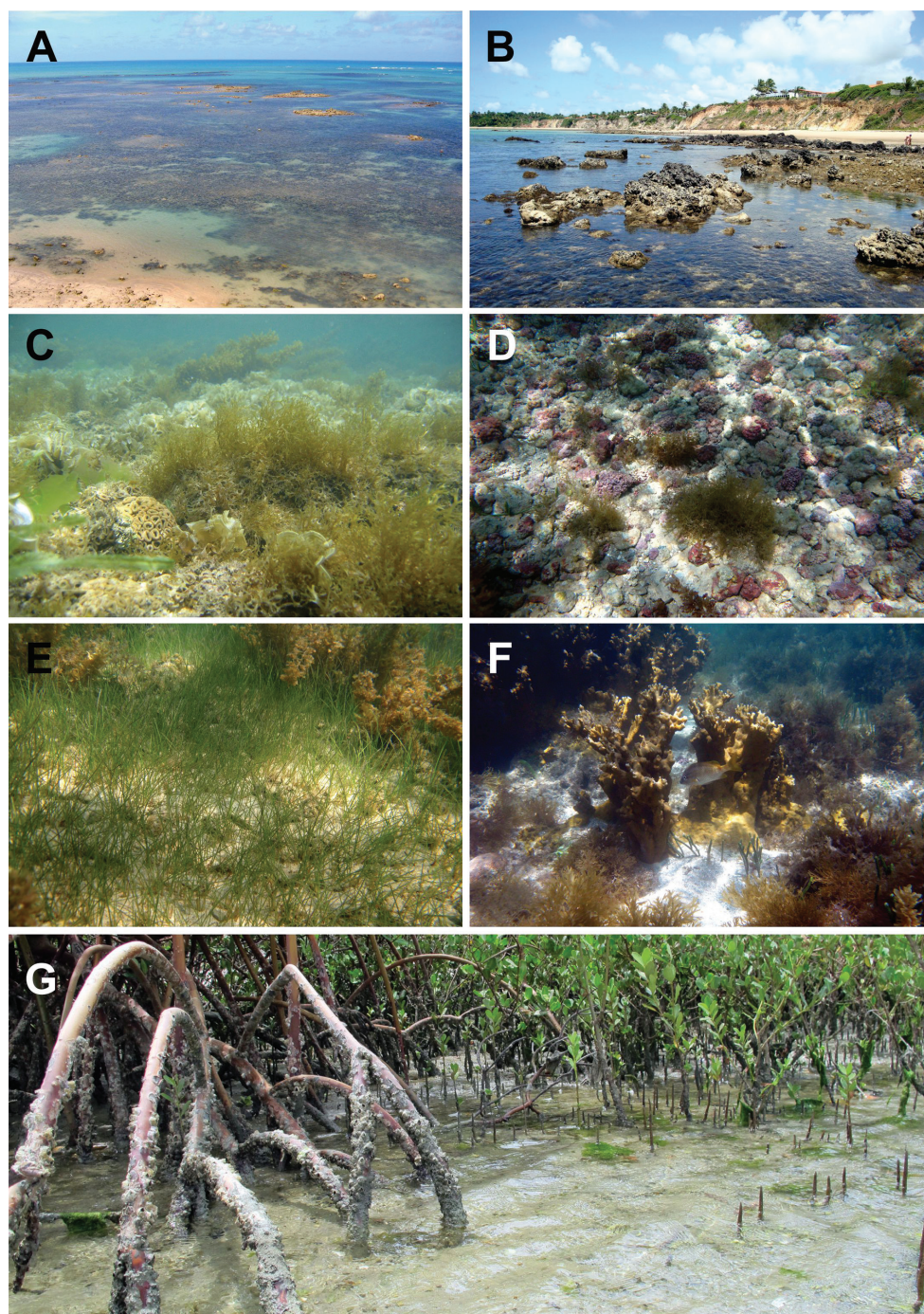


Figure 2. Some littoral environments and shallow-water biotopes used as habitats by sea stars in northeastern Brazil. **A** Fringing reef **B** Beach rocks **C** Algae banks **D** Rhodolith bed **E** Seagrass bed **F** Patch reef, and **G** Mangroves. Photos: Thelma LP Dias.

Abbreviations: Brazilian states – Ceará (CE), Piauí (PI), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE), Bahia (BA), Paraná (PR), Rio de Janeiro (RJ), Rio Grande do Sul (RS), Santa Catarina (SC), São Paulo (SP).

Acronyms: UFPB.Ech: Echinodermata Collection from Universidade Federal da Paraíba. MZUFBA: Museum of the Federal University of Bahia. MZUSP: Museum of Zoology of the University of São Paulo. MNRJ: National Museum of Rio de Janeiro.

Results

A total of 21 species, belonging to five orders, 10 families and 12 genera were identified. These are listed and described below, following the taxonomic organization of Clark and Downey (1992).

Checklist of Starfishes from northeastern Brazil

Phylum Echinodermata Brugière, 1791

Class ASTEROIDEA de Blainville, 1830

Order Paxillosida Perrier, 1884

Family Luidiidae Verrill, 1900

Luidia alternata alternata (Say, 1825)

Luidia clathrata (Say, 1825)

Luidia ludwigi scotti Bell, 1917

Luidia senegalensis (Lamarck, 1816)

Family Astropectinidae Gray, 1840

Astropecten acutiradiatus Tortonese, 1956

Astropecten alligator Perrier, 1881

Astropecten brasiliensis Müller & Troschel, 1842

Astropecten cingulatus Sladen, 1833

Astropecten duplicatus Gray, 1840

Astropecten marginatus Gray, 1840

Order Valvatida Perrier, 1884

Family Asterinidae Gray, 1840

Asterinides folium (Lütken, 1860)

Family Mithrodiidae Viguier, 1878

Mithrodia clavigera (Lamarck, 1816)

Family Oreasteridae Fisher, 1911

Oreaster reticulatus (Linnaeus, 1758)

Family Goniasteridae Forbes, 184

Nymphaster arenatus (Perrier, 1881)

Plinthaster dentatus (Perrier, 1884)

Order Velatida Perrier, 1884

- Family Pterasteridae Perrier, 1875
 - Calyptraster coa* Sladen, 1882
- Family Ophidiasteridae Verrill, 1870
 - Linckia guildingi* Gray, 1840
 - Narcissia trigonaria* Sladen, 1889
- Order Spinulosida Perrier, 1884
 - Family Echinasteridae Verrill, 1867
 - Echinaster (Othilia) brasiliensis* Müller & Troschel, 1842
 - Echinaster (Othilia) echinophorus* (Lamarck, 1816)
- Order Forcipulatida Perrier, 1884
 - Family Asteroiidae Gray, 1840
 - Coscinasterias tenuispina* (Lamarck, 1816)

Systematics

Order Paxillosida Perrier, 1884

Family Luidiidae Sladen, 1889

Luidia alternata alternata (Say, 1825)

Figure 3a–d

Asterias alternata Say, 1825: 144–145.

Luidia alternata Lütken, 1859: 42–43. Brito 1968: 12–13, pl. 3, fig. 4. Tommasi 1970: 8, fig. 24. Tommasi and Aron 1987: 5. Tommasi et al. 1988: 6. Ventura et al. 2007: 236. Miranda et al. 2012: 9.

Luidia granulosa Perrier, 1869: 109–110, pl. 2, fig. 18.

Luidia variegata Perrier, 1875: 337.

Luidia numidica Koehler, 1911: 3, pl. 1, figs 8–11.

Luidia quequenensis Bernasconi, 1942: 253. Tommasi 1970: 8, fig. 23. Carrera-Rodriguez and Tommasi 1977: 62, 65.

Luidia bernasconiae A.H.Clark, 1945: 19–21.

Luidia alternata var. *numidica* Madsen, 1950: 206–209, fig. 9.

Luidia alternata numidica A.M.Clark, 1953: 388–389, pl. 41, fig. 1.

Luidia alternata alternata Clark & Downey, 1992: 8–9; Magalhães et al. 2005: 63.

Material examined. Paraíba: 6°46'S; 34°50'W, 1spec., UFPB/ECH.877, 13.II.1981, 14m; 7°01'S; 34°41'W, 1spec., UFPB/ECH.876, 13.II.1981, 24m; 7°04"S; 34°41'W, 1spec., UFPB/ECH.879, 16.II.1981, 22m.

Type locality. Dry Tortugas, Florida Keys, Florida (Clark and Downey 1992)–Neotype.

Description. Body pentagonal (Fig. 3a, b). Five elongate and thin arms. Abactinal surface with paxillae (Fig. 3a). Carinal paxillae smaller than adradial paxillae, with 1–4

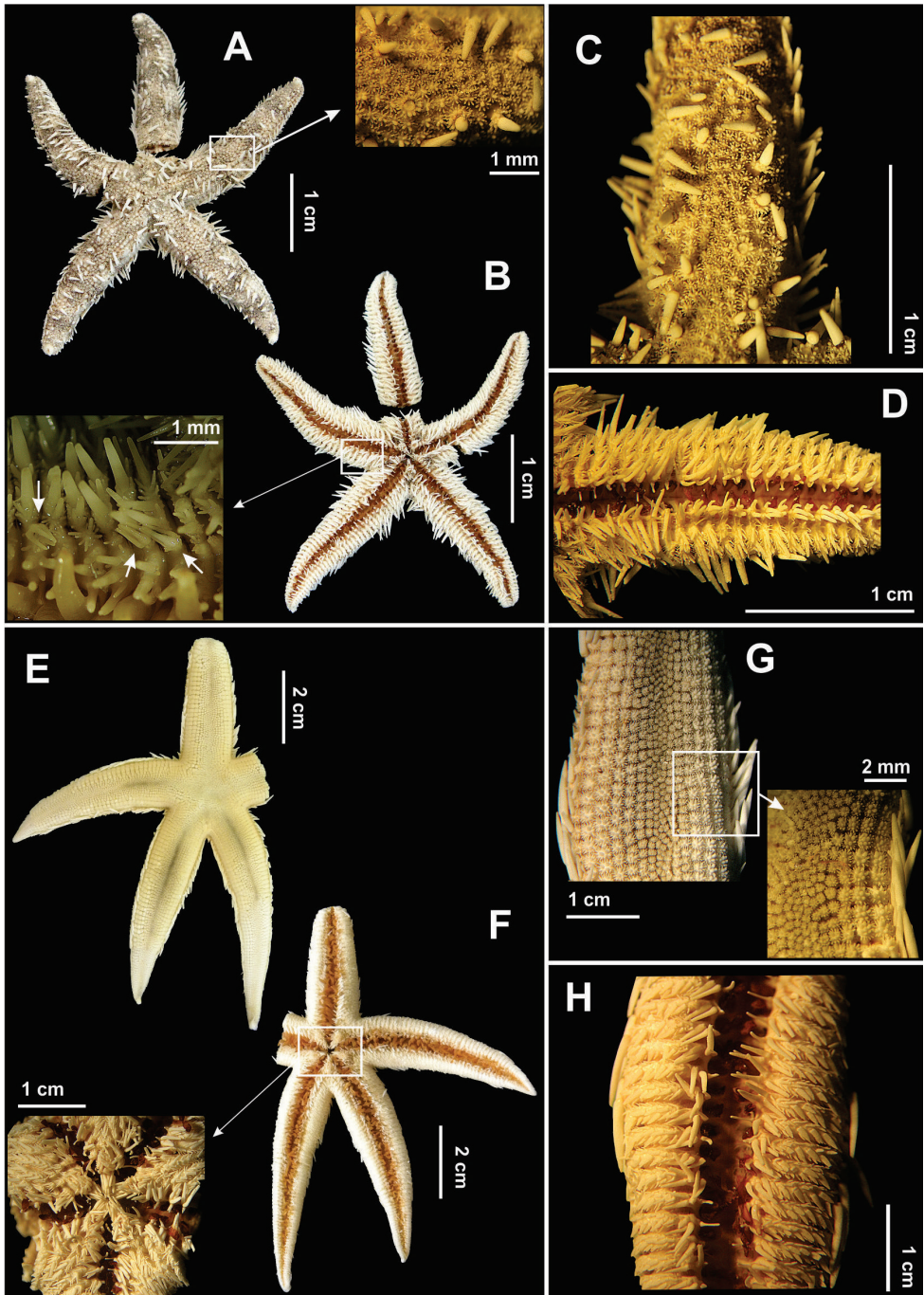


Figure 3. Some species of the family Luidiidae recorded in northeastern Brazil. *Luidia alternata alternata* (A–D). **A** Abactinal view, in detail the paxilla **B** Actinal view, in detail the pedicellariae **C** Abactinal view of the arm **D** Actinal view of the arm; *Luidia clathrata* (E–H) **E** Abactinal view **F** Actinal view, in detail the mouth **G** Abactinal view of the arm, in detail the paxilla, and **H** Actinal view of the arm.

blunt central spinelets and with one or two series of marginal spinelets, numbering 12–20 per series. One of the central spines is slightly longer than remaining spines. Paxillae rounded and arranged into regular transversal rows. Some adradial paxillae with one long, conical and pointed central spine (~1.90 mm) (Fig. 3c). Inferomarginal plate with 1 or 2 long, thin spines (~1.76 mm), placed vertically and forming a well defined marginal row. Actinal surface with inferomarginal plates densely covered with spines of diverse shapes and sizes, there being 1–3 longer spines located centrally (Fig. 3c, d). Adambulacral plate with 4 spines placed vertically. The adambulacral spine is the smallest, being slightly curved and compressed. The two subambulacral spines are subequal in shape and size. A short spine is located laterally to the most external spine. Oral spines narrow and elongate. With bi, tri and tetraalvular pedicellariae on actinal surface (Fig. 3b).

Colour. Abactinal surface white or cream-coloured, with dark transversal bands. The colour of these bands varies, and may be brown, black, green, or purple. Actinal surface whitish or beige.

Distribution. North Carolina, the Bahamas, Florida, Gulf of Mexico, Cuba, Jamaica, Honduras, Puerto Rico, Panama, Colombia, Venezuela, Brazil, Uruguay, and Argentina (Bernasconi 1943, Tommasi 1958, Downey 1973, Walenkamp 1976, Clark and Downey 1992, Hendler et al. 1995, Ventura et al. 2007, Alvarado et al. 2008). In Brazil from AL, BA, RJ, and SP (Verrill 1915, Brito 1962, 1968, Tommasi 1970, Magalhães et al. 2005, Miranda et al. 2012). This is the first record of the species for the coast of Paraíba. From 1 to 200 m in depth (Clark and Downey 2002), most common between 10 and 30 m.

Remarks. The main characters distinguishing *Luidia alternata alternata* from the remaining species of the genus that occur in the Western Atlantic are their colour and the presence of long conical spines on the adradial paxillae. The abactinal colouration is distinctive. The nominal subspecies differs from its congeneric form *Luidia alternata numidica* Koehler, 1911, from West Africa, for attaining a larger size and for having longer paxillar spines. Clark (1982) provided a good discussion on the synonymy of the nominal subspecies and designates a neotype. Specimens analysed in this study are young individuals that may attain 200 mm along its larger ray. Furthermore, our specimens presented no morphological variations, agreeing with the descriptions of this species. Despite not receiving much attention in recent taxonomic surveys, pedicellariae are an important taxonomic character to distinguish species of asteroids. Clark (1982) and Clark and Downey (1992) furnished excellent illustrations of the species of *Luidia* known from the Atlantic.

Ecological notes. This subspecies is primarily associated with sandy and muddy bottoms. It may also be found in mangroves or associated with fragments of shells and calcareous algae (Clark and Downey 1992, Benavides-Serrato et al. 2011). According to Hendler et al. (1995), the subspecies does not occur in large numbers, but is often found among the accompanying fauna in trawling nets. *L. alternata alternata* is carnivorous, feeding on epifaunal organisms, especially other echinoderms.

***Luidia clathrata* (Say, 1825)**

Figure 3e–h

Asterias clathrata Say, 1825: 142.*Luidia clathrata* Lütken, 1859: 37–39. Rathbun 1879: 150. Bernasconi 1943: 6–7.

Tommasi 1970: 8. Magalhães et al. 2005: 63.

Luidia clathrata Lütken, 1859: 37. Tommasi 1958: 9, pl. 2, fig. 1; 1970: 8, fig. 22.

Brito 1962: 4; 1968: 11–12, pl. 2, fig. 2. Carrera-Rodriguez and Tommasi 1977:

63–64. Tommasi and Aron 1987: 3. Tommasi et al. 1988: 6. Magalhães et al.

2005: 63. Ventura et al. 2007: 237. Manso et al. 2008: 185, fig. 7a–e. Lima and

Fernandes 2009: 58. Xavier 2010: 75.

Material examined. Paraíba: 6°57'S; 34°41'W, 2 spec., UFPB/ECH.875, 12.II.1981, 26m.**Type locality.** Probably no longer existant (Clark and Downey 1992).

Description. Five long and narrow arms (Fig. 3e, f). Abactinal surface paxillar. Lateral paxillae quadrangular, forming three regular rows (Fig. 3g). Carinal paxillae small, smaller than lateral paxillae. Dorsal paxillae rounded, small, with 1–6 short, blunt, central spinelets and 6–18 slender, marginal spinelets. Inferomarginal plates with two long, pointed, conical spines (~2.58 mm), positioned vertically, the inferior one the largest. Actinal surface with inferomarginal plates densely covered with flattened, lanceolate spines (Fig. 3f). A row of short, actinolateral plates, with 1–3 short, lanceolate, divergent spines. Ambulacral plates with three spines placed vertically (Fig. 3h). The adambulacral spine is the smallest, being slightly curved and compressed. Of the two subambulacral spines, the inner one is longer and thicker than the outer spine. Oral spines long (~1.32 mm), thin and pointed, forming dense tufts on the inner angle of the jaw (Fig. 3f). Ocular plate granulose and elongate.

Colour. Abactinal surface bluish-gray, frequently with a darker line occupying the carinal region of the arm and disk. Hendler et al. (1995) cite other colour patters for the abactinal surface: brown, rose and salmon. Actinal surface white or cream-coloured.

Distribution. Bermuda, Gulf of Mexico, Belize, Honduras, Nicaragua, Panama, Colombia, Venezuela, and Brazil (Downey 1973, Clark and Downey 1992, Hendler et al. 1995, Alvarado et al. 2008, Benavides-Serrato et al. 2005). In Brazil: PE, BA, RJ, SP, and SC (Rathbun 1879, Bernasconi 1943, Tommasi 1958, 1970, Brito 1960, 1962, Walenkamp 1976, Magalhães et al. 2005, Lima and Fernandes 2009, Xavier 2010). This study records the species for the first time in the State of Paraíba. From intertidal to 175 m in depth (Ventura et al. 2007), being most common in depths under 40 m (Hendler et al. 1995).

Remarks. *Luidia clathrata* differs from *L. alternata alternata* for not having the abactinal surface spinulose. It differs from *L. senegalensis* for having only 5 arms and from *L. ludwigi scotti* for not having pedicellariae. According to Walenkamp (1976), the number of central spinelets on the paxillae and of inferomarginal spines increases with ontological development, the maximum numbers being, respectively, 7 and 3. In

this study the examined specimen had only two inferomarginal spines, and 1–6 central spinelets on the paxillae. These characters indicate a juvenile individual. According to Hendler et al. (1995), adult individuals may attain 20 to 30 cm in disk diameter. Knott and Hopkins (1998) recognized two morphotypes of *L. clathrata* for the Colombian Caribbean, one with a gray colour and the other with three colours, which were separated by Hopkins and Knott (2010) into *L. clathrata* and *L. lawrencei*. Those authors also established and described a neotype for *L. clathrata*.

Ecological notes. This species lives in sandy or muddy areas with low hydrodynamism near the coast, such as bays and lagoons, and is also found in mangroves and regions with low salinity. Further away from the coast, it lives in substrates with sand, mud and gravel (Machado et al. 2008, Benavides-Serrato et al. 2011). It feeds on a great variety of prey, including molluscs, crustaceans, and ophiuroids (Hendler et al. 1995). Like *L. alternata* and *L. senegalensis*, *Ludia clathrata* is host for the small polychaete *Podarke obscura* Verrill, 1873, that lives in the interior of its ambulacral groove. *L. clathrata* may form dense populations, and is thus frequently captured in trawling nets used in shrimp fisheries (McClintock and Lawrence 1985, Hendler et al. 1995). Presently it is considered to be a species vulnerable to extinction along the Brazilian coast (Machado et al. 2008).

***Luidia ludwigi scotti* Bell, 1917**

Figure 4a–d

Luidia scotti Bell, 1917: 8–9. Tommasi 1970: 8, fig. 25. Carrera-Rodriguez and Tommasi 1977: 62, 65–66.

Luidia doello-juradoi Bernasconi, 1941: 117; 1943: 8–11. Brito 1962: 3.

Luidia rosaurae John & Clark, 1954: 142–145.

Luidia doello-juradoi Brito, 1968: 12, pl. 3, fig. 5.

Luidia ludwigi Walenkamp, 1976: 32–37, fig. 9, pl. 2, figs 1–3, pl. 4, fig. 3. Machado et al. 2008: 179–180. Xavier 2010: 75.

Luidia ludwigi scotti A.M. Clark, 1982: 171–173. Tommasi 1985: 3. Tommasi et al. 1988: 6. Manso 1989: 357.

Luidia rosaurae John & Clark, 1954: 142–145, pl. 6, fig. 1.

Material examined. Paraíba: 6°39'05"S; 34°49'W, 1 spec., UFPB/ECH.878, 28.V.1981, 20m.

Type locality. Rio de Janeiro, Brazil (Clark and Downey 1992).

Description. Body flattened. Five arms that taper gradually towards their extremities (Fig. 4a, b). Abactinal surface with paxillae (Fig. 4a). Dorsal paxillae small, ordered, with 1–6 central, short, blunt spinelets, and 18 marginal, slender, and denticulate spinelets (Fig. 4c). Adradial paxillae rectangular or quadrangular, slightly larger than the carinal paxillae. Inferomarginal plates with one pointed, elongate spine (~2.04 mm) forming the marginal fringe (Fig. 4a). The remaining part of the plate is covered

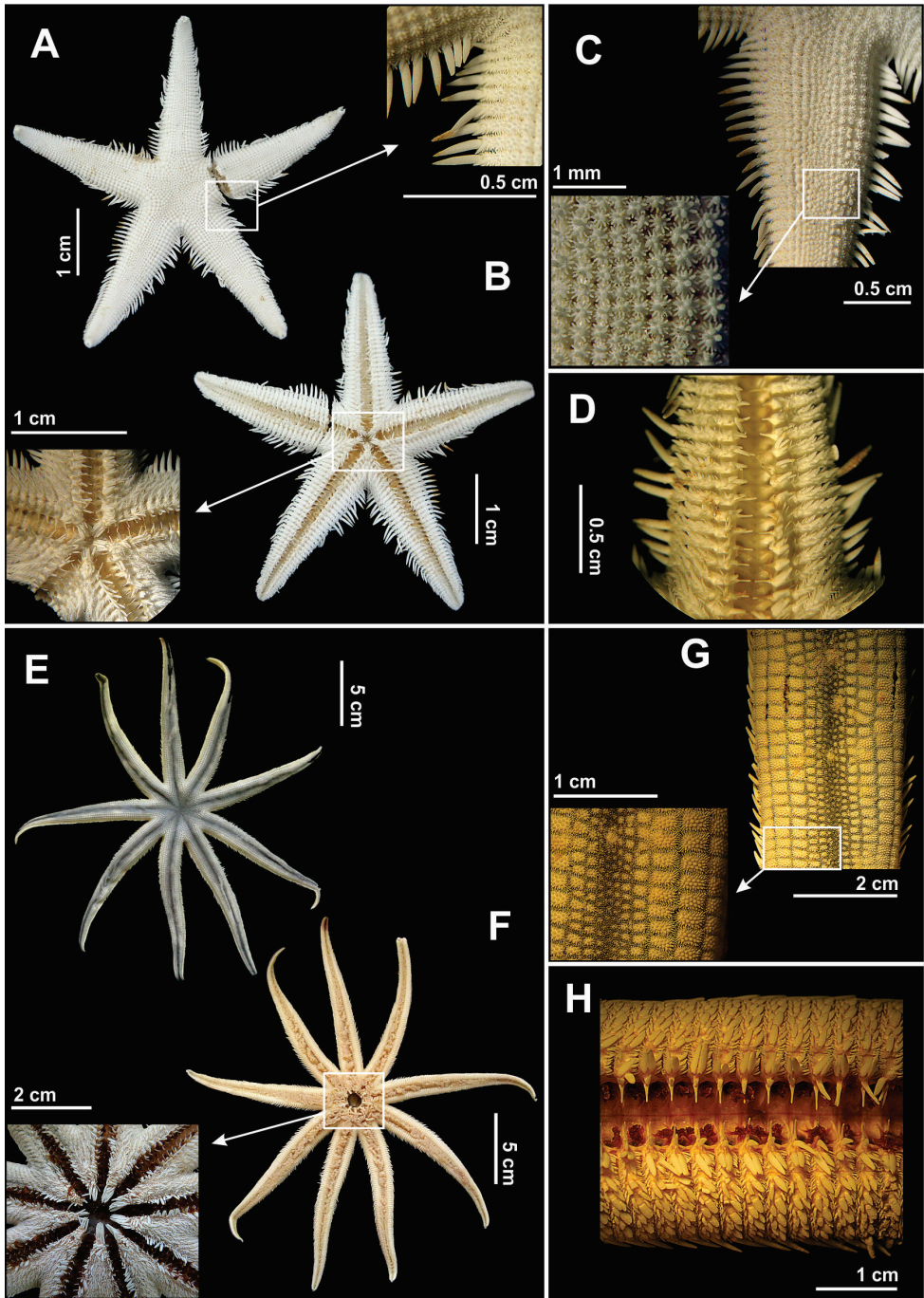


Figure 4. Some species of the family Luidiidae recorded in northeastern Brazil. *Luidia ludwigi scotti* (A–D) **A** Abactinal view, in detail abactinal intermediate area **B** Actinal view, in detail the mouth **C** Abactinal view of the arm, in detail the paxilla **D** Actinal view. *Luidia senegalensis* (E–H) **E** Abactinal view **F** Actinal view, in detail the mouth **G** Abactinal view of the arm, in detail the paxilla, and **H** Actinal view of the arm.

by short, hyaline and denticulate spinelets. Actinal surface with inferomarginal plates, densely covered by flattened and lanceolate spines (Fig. b, d). Actinolateral plate with three short, slender, divergent spines. The median of these is the largest. The ambulacral spine long, flattened and slender (Fig. 4d). Bivalved pedicellariae present only on the actinal surface, mainly on the ventro-lateral plates and in the areas close to the arms, never occurring on the abactinal surface. Oral spines slender, long (~1.18 mm) with blunt tip, forming a bundle of spines at apex of jaw (Fig. 4c).

Colour. The colour pattern on the aboral surface of the body is very variable. Some specimens may be whitish with black spots on arms, others are brown with white spots on arms. Most, however, have the arms more or less banded with alternating white and brown stripes (Walenkamp 1976). Benavides-Serrato et al. (2011) and Clark and Downey (1992) observed specimens with dark pink spots in the center of the dorsal surface of the disc and transversal bands of the same tone on the arms. Oral surface with colour varying between white and cream. When observed in alcohol they are uniformly white.

Distribution. Florida, Gulf of Mexico, Colombia, Venezuela, Guyana, French Guyana, Brazil, and Argentina (Mar del Plata) (Bernasconi 1943, Tommasi 1970, Clark and Downey 1992, Benavides-Serrato et al. 2005). In Brazil: RJ, SP, and SC (Brito 1962, 1968, Xavier 2010). This is the first record of the species for the littoral of northeast Brazil. From 20 to 126 m in depth. Clark and Downey (1992) considered the previous record at 5 m for the State of São Paulo to be doubtful. Thus the present study expands the bathymetric distribution to 20 m deep, previously established at 33–126 m.

Remarks. This subspecies may be distinguished from other taxa in the genus by the presence of pedicellariae with three or four well-developed valves on the actinal surface, the delicate structure of the paxillae, and the slightly triangular shape of the arms, which become narrow distally. *Luidia clathrata* is similar to *L. ludwigi scotti*, but may be distinguished from it by having a stronger actinal skeleton and by the absence of pedicellariae. The synonymy between *Luidia rosaurae* John & Clark, 1954 and *L. scotti* was proposed by Clark (1982), who observed that the differences in the inferomarginal spines previously established between the two species were insignificant and unable to support the independence of the two species. Furthermore, with the observations of Walenkamp (1976) that *L. rosaurae* is conspecific with *L. ludwigi* Fisher, 1906, Clark and Downey (1992) recognized the subspecies *Luidia ludwigi scotti* for specimens from the Atlantic, as these have a paxillar arrangement that is distinct from the remaining species previously cited. According to Clark and Downey (1992), the relationships between *L. patriae* Bernasconi, 1941 and this subspecies still need to be investigated. The specimen analysed in this study, even though representing a juvenile individual, did not present significant morphological variations when compared with the characters described for adult specimens, indicating that the morphological characters of *L. ludwigi scotti* do not vary significantly during ontogeny.

Ecological notes. This subspecies occurs in non-consolidated sediments containing fine or coarse sand (Machado et al. 2008). In contrast to other taxa of *Luidia*, which

do not present prey selectivity, in *Luidia ludwigi scotti* only eight different food types have been recorded, of which bivalves, foraminiferans and ophiuroids are their main prey (Benavides-Serrato et al. 2011). The presence of different prey species of distinct sizes in the stomachs of *L. ludwigi scotti* probably reflects a response to competition and coexistence with other species of sea-stars (Brögger and Penchaszadeh 2008).

***Luidia senegalensis* (Lamarck, 1816)**

Figures 4e–h, 12a

Asterias senegalensis Lamarck, 1816: 567.

Luidia senegalensis Müller & Troschel, 1842: 78. Tommasi 1958: 9, pl. 2, fig. 1; 1970: 8, fig. 21; 1985: 3. Brito 1968: 10–11, pl. 3, fig. 1. Lima-Verde 1969: 10. Nomura and Fausto Filho 1966: 19. Fernandes et al. 2002: 422. Magalhães et al. 2005: 63. Manso et al. 2008: 185, fig 8c–e. Lima and Fernandes 2009: 58. Xavier 2010: 75. *Luidia marcgravii* Steenstrup in Lütken 1859: 43–46.

Material examined. Rio Grande do Norte: Timbau Beach, 3 spec., UFPB/ECH.1582, 28.II.1980; Areia Branca, Ponta do Mel, 1spec., UFPB/ECH.1428, 23.VI.1982. Paraíba: Lucena, Costinha Beach, 5 spec., UFPB/ECH.1673, 08.XI.2003; Cabedelo, Miramar Beach, 4spec., UFPB/ECH.1256, 03.II.1983; Cabedelo, Santa Catarina Beach, 1spec., UFPB/ECH.1583, 18.V.2007; Paraíba do Norte River Estuary, 1spec., UFPB/ECH.89, 18.06.1980; 1spec., UFPB/ECH.1586. 13.VI.1983.

Type locality. Supposedly Senegal ('L' océan d'Afrique, les côtes du Senegal'), but probably West Indies (Clark and Downey 1992).

Description. Body flattened. Disk rounded. Nine long and narrow arms (rarely 7) (Fig. 4e, f). Paxillae on abactinal surface. Paxillae small, arranged irregularly, occupying center of disk and of arms. Paxillae of carinal regions rounded, with 1–4 central, short, rounded spinelets and 12–16 marginal spinelets disposed into two rows. Adradial paxillae quadrangular, disposed in regular longitudinal and transversal rows, bearing 4–10 central, short, rounded spines (Fig. 4g). Inferomarginal plates with two short, conical and slightly compressed spines (~2.20 mm), the upper one being the smallest. Towards the mouth the inferomarginal plates are covered by short, lanceolate spines (Fig. 4f). Between these and the lateral margins slender spinelets occur. Adambulacral plates with four spines, two elongate, compressed and slightly curved adambulacral spines, and two elongate, flattened and lanceolate subambulacral spines (Fig. 4h). Oral spines long (~2.59 mm) and thin, forming a dense tuft of spines on the apex of jaw. Ocular plates well developed and grunuliform. Pedicellariae absent.

Colour. Dorsally bluish-grey or greenish-gray, with a strong dark line along the central region of the disk and of the arms. The actinal surface is white to cream-coloured.

Distribution. Florida, Cuba, Jamaica, Honduras, Nicaragua, Costa Rica, Panama, Venezuela and Brazil (Tommasi 1958, Clark 1982, Abreu-Pérez et al. 2005, Alvarado et al. 2008, del Valle García et al. 2008). In Brazil: PI, CE, PB, PE, AL, BA,

RJ, SP, and SC (Rathbun 1879, Verrill 1915, Bernasconi 1943, Krau 1950, Tommasi 1958, 1970, Brito 1962, 1968, Lima-Verde 1969, Fernandes et al. 2002, Magalhães et al. 2005, Gondim et al. 2008, 2013, Gondim and Giacometti 2010, Xavier 2010, Miranda et al. 2012). This study provides the first record for the coast of Rio Grande do Norte. From 1 to 64 m in depth, being rare below 40 m (Clark and Downey 1992).

Remarks. Distinguished from the remaining species from Brazil by the presence of 7 to 9 arms. *Luidia barbadensis* Perrier, 1881, recorded for Bahamas, Florida, Gulf of Mexico and south Brazil is the closest species, but it may be distinguished from *L. senegalensis* for having 6 arms, inframarginal plates with two long and narrow spines, and the usual presence of pedicellariae. Walenkamp (1979) identified one specimen with 6 arms from Guyana as *L. senegalensis*. His identification was questioned for some time, but the presence of dark bands on the carinal region of the arms and disk and the depth of collection (32 m, while the minimum known depth of *L. barbadensis* is 73 m) confirm the validity of this identification (Clark and Downey 1992). Our observation of both juvenile (dd ≤ 15 cm) and adult individuals permitted the conclusion that morphological characters do not vary during ontogeny. Thus forms with less than 7 arms or more than 9 arms (this later condition never having been observed in nature) must be the result of failures during metamorphosis (Hotchkiss 2000). As for the remaining Paxillosida, the structure of the paxillae represent a key taxonomic character for the identification of species.

Ecological notes. The species lives in environments of low hydrodynamism, in sediment containing sand, mud, or a combination of both of these (Hendler et al. 1995). It feeds mainly on molluscs, but also of other echinoderms such as sea-stars of the genus *Astropecten* and irregular echinoids, as well as ophiuroids, copepods, decapods, scaphopods, and polychaetes (Penchaszadeh and Lera 1983). Sometimes a small commensal crustacean (*Minyoceras angustus* Dana, 1852) is found in the interior of its ambulacrum. This crustacean was also observed in *L. clathrata* (Brito 1960). According to Hendler et al. (1995), individuals may attain 30–40 cm in disk diameter (dd), and attain sexual maturity when at 15 cm in diameter. Presently it is considered vulnerable to extinction along the Brazilian littoral. The main causes of population decline are its high susceptibility to the effects of pollution of the water column and the frequent accidental capture in trawling nets (Machado et al. 2008).

Family Astropectinidae Gray, 1840

Astropecten alligator Perrier, 1881

Figure 5a–d

Astropecten alligator Perrier, 1881: 30.

Astropecten nuttingi Verrill, 1915: 181, pl. 12, fig. 2e, pl. 21, figs 1–2.

Material examined. Paraíba: 7°01'S; 34°41'05"W, 1 spec., UFPB/ECH.881, 13.II.1981, 24m.

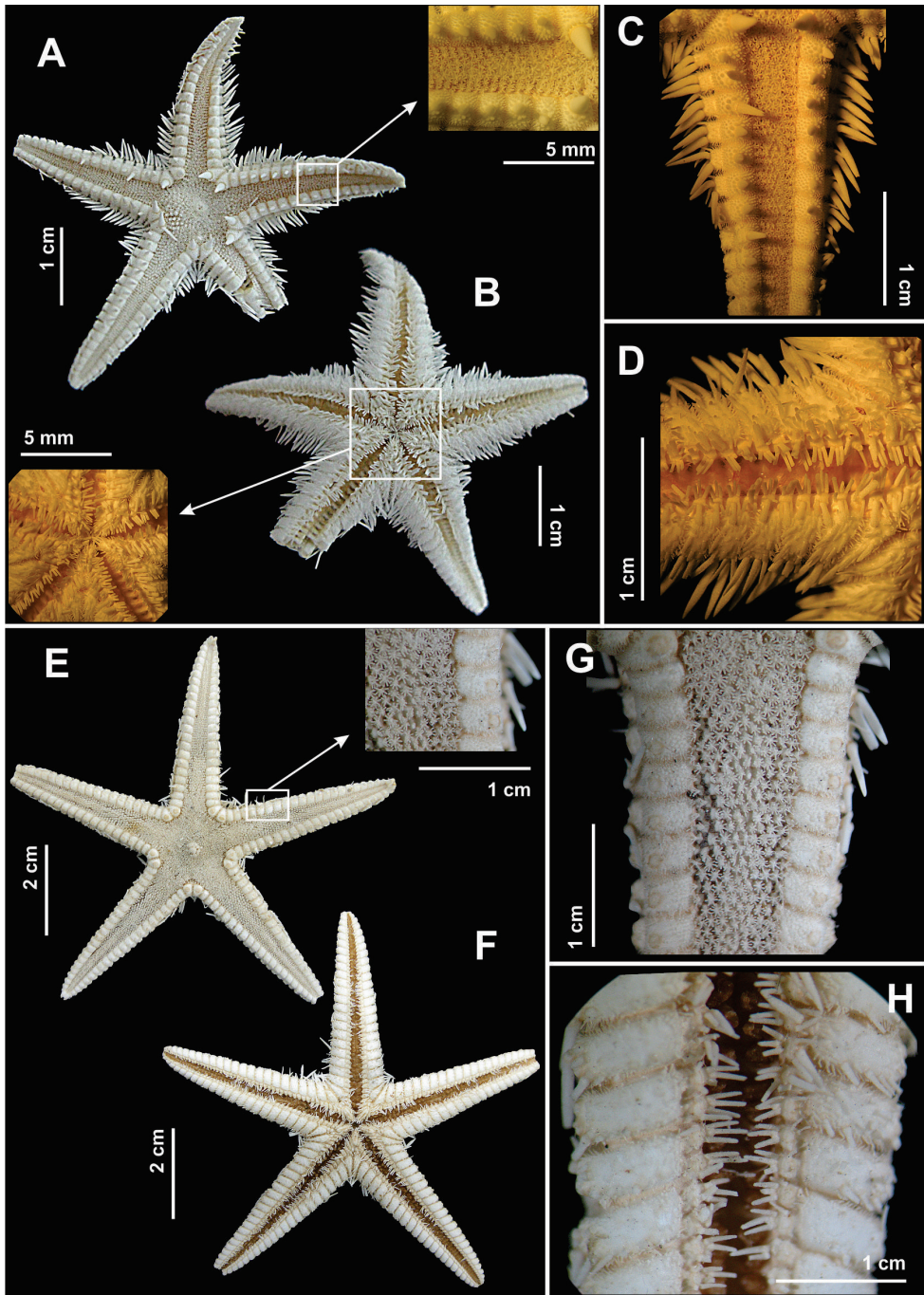


Figure 5. Some species of the family Astropectinidae recorded in northeastern Brazil. *Astropecten alligator* (A–D) **A** Abactinal view, in detail of the paxilla **B** Actinal view, in detail of mouth **C** Abactinal view of the arm **D** Actinal view of the arm; *Astropecten cingulatus* (E–H) **E** Abactinal view, in detail the paxilla **F** Actinal view **G** Abactinal view of the arm, and **H** Actinal view of the arm.

Type locality. Alligator Reef, Florida Keys, Florida (Clark and Downey 1992).

Description. Body flattened dorso-ventrally. Disk small, with five long and narrow arms (~4.93 mm) (Fig. 5a, b). Epiproctal cone pronounced (this region of the disk and the surrounding areas are inflated) (Fig. 5a). Abactinal surface flat and covered by small paxillae disposed in regular rows (Fig. 5a). Paxillae with a central spinelet and 8–10 (usually 9) thick, marginal spinelets with blunt extremities. Superomarginal plates short (~1.14 mm) and narrow (~1.59 mm), covered by short and blunt spinelets, giving a granulose appearance to animals. Each of these plates has an elongate, conical and pointed spine (Fig. 5a, c), which has the same length from the interbranchial area to the extremity of each arm. Inferomarginal plates with two long, flattened and pointed spines, placed in parallel to each other. These plates are also covered by short and narrow spinelets. Towards the mouth the inferomarginal plates are covered by many flattened and pointed spines, which become elongated at the margins. Adambulacral plates with three long, flattened adambulacral spines, placed in parallel to each other, the median one being slightly longer than the other two (Fig. 5d). There are three to four long and flattened subambulacral spines, the median of which is longer and wider than the other two.

Colour. Reddish-brown dorsally, with conspicuous dark bands along the center of each arm (Clark and Downey 1992), or uniformly orange-red.

Distribution. North Carolina, the Bahamas, Florida, Honduras, Nicaragua Colombia, and Brazil (Verrill 1915, Gray et al. 1968, Clark and Downey 1992, Benavides-Serrato et al. 2005, 2011, Alvarado et al. 2008). In Brazil: Benavides-Serrato et al. (2005) cite its occurrence in the north of Brazil. This study expands the distribution southward to the State of Paraíba, being the first reference for the northeast region of Brazil. From 22 to 576 m in depth (Benavides-Serrato et al. 2011), most frequent between 22 and 114 m (Clark and Downey 1992).

Remarks. *Astropecten alligator* differs from the remaining species in the genus recorded for Brazil for presenting a single, elongate, erect conical spine on all the superomarginal plates. This character is present in both juvenile and adult individuals (dd = 41.0 mm). For a long time it was believed that Perrier (1881) had described *A. alligator* based on a juvenile specimen and the recognition of this species remained uncertain. Clark and Downey (1992) analysed the type material of *A. alligator*. They were able to validate the species and consider *Astropecten nuttingi* Verrill, 1915 a junior synonym of this taxon. In a molecular phylogenetic analysis of *Astropecten*, Zulliger and Lessios (2010) concluded that *A. alligator* and *A. americanus* probably belong to the same species and that the species needs to be extensively revised.

Ecological notes. Usually inhabits muddy environments, but may also be found associated to communities of azooxanthellate corals (Benavides-Serrato et al. 2011). It is common along the coast of Florida (Clark and Downey 1992), but for a long time it has been erroneously cited there as *Astropecten nuttingi*. In other areas *A. alligator* is a rare species, being little cited in the literature.

***Astropecten articulatus* (Say, 1825)**

Asterias articulata Say, 1825: 144.

Astropecten dubius Gray, 1840: 182.

Asterias aranciaca Gould, 1841: 349 (non *Asterias aranciaca* Linnaeus, 1758).

Astropecten articulatus Müller & Troschel, 1842: 72. Tommasi 1970: 6, fig. 17. Tommasi et al. 1988: 5. Manso 1989: 357.

Astropecten buschi Müller & Troschel, 1843 (a variety of *Astropecten articulatus* (Say, 1825) according to Doderlein (1917)).

Astropecten articulatus dubius Verrill, 1915: 165.

Astropecten articulatus var. *valenciennesi* A.H.Clark, 1939: 442.

Astropecten articulatus duplicatus Zoppi de Roa, 1967: 277, fig. 6. (non *Astropecten duplicatus* Gray, 1840).

Material examined. Caraguatatuba, São Paulo, 1 spec., MZUSP484, 16.X.2001, 19m.

Type locality. Florida (Clark and Downey 1992).

Description. Body pentagonal, flattened dorso-ventrally. Five long and narrow arms (length of arm corresponds to approximately four times its width), which become gradually narrow towards tips. Abactinal surface with paxillae. Paxillae disposed regularly, carenals smaller than adradials. 1–6 short, thick and blunt paxillar spines in center, 10–16 in margins. Supermarginal plates granulose, with a large spine (~1.54 mm) positioned internally on the interbrachial plates. Some distal supermarginal plates have a short spine positioned more externally. Inferomarginal plates with two elongate, flattened and pointed marginal spines, positioned horizontally. Small oral spine. Three adambulacral spines divergent, the median one being the largest.

Colour. Dorsally dark blue or purple in paxillar region. Superomarginal plates white or orange. Oral surface white of beige (Hendler et al. 1995; Benavides-Serrato et al. 2011).

Distribution. North Carolina, Florida, the Bahamas, Mexico, Cuba, Puerto Rico, Dominican Republic, Panama, Colombia, Venezuela, Brazil, and Uruguay (Tommasi 1970, Clark and Downey 1992, Hendler et al. 1995, Alvarado 2011). In Brazil: PI, CE, RJ, SP, and RS (Lima-Verde 1969, Netto 2006). From 0 to 550 m in depth, being most common between 5 and 20 m (Clark and Downey 1992, Hendler et al. 1995).

Remarks. *Astropecten articulatus* differs from the congeneric *A. cingulatus* for having a spine or tubercle on the distal supermarginal plates, two flat spines on each inferomarginal plate and subambulacral spines larger than the adambulacral spines. The original description of *A. articulatus* Say (1825) is excellent, but the emphasis given by this author on the presence of spines and tubercles resulted in some uncertainty regarding the validity of *A. duplicatus* (Gray, 1840) (Clark and Downey 1992). According to Clark and Courtman-Stock (1976) and Clark and Downey (1992) the confidence in the presence of spines on the superomarginal plates as a specific criterion is doubtful. As in other species of the genus, *A. articulatus* presents a series of morphological variations. Verrill (1915) provides a good discussion of these variations, and

stresses the differences found between juvenile and adult individuals. We have only been able to examine a single juvenile specimen, which nevertheless presented all the diagnostic characters of the adults.

Ecological notes. Inhabits sandy environments. According to Benavides-Serrato et al. (2011) and Hendler et al. (1995), this species is common offshore over continental shelf, being particularly abundant in North Carolina. *Astropecten articulatus* is a voracious and non-selective predator (Hendler et al. 1995). Wells et al. (1961) recorded 91 food items for 124 specimens collected in North Carolina, gastropods, bivalves, and scaphopods being the most important items. Small crustaceans, juveniles of *Mellita* sp. and *A. articulatus* itself were also recorded as food items for the species, although in a lower level of importance (Hendler et al. 1995).

Astropecten brasiliensis Müller & Troschel, 1842

Astropecten brasiliensis Müller & Troschel, 1842: 68. Tommasi et al. 1988: 5. Manso 1989: 357. Fernandes et al. 2002: 422. Netto 2006: 25–26, pl. 2a, fig. 16a. Ventura et al. 2007: 230. Machado et al. 2008: 350. Lima and Fernandes 2009: 58. Xavier 2010: 75. Miranda et al. 2012: 143, 144.

Astropecten braziliensis Rathbun, 1879: 150. Tommasi 1970: 6.

Astropecten brasiliensis riensis Döderlein, 1917: 84.

Astropecten brasiliensis armatus Jonh, 1948: 503.

Astropecten armatus brasiliensis Tortonese, 1956: 329. Tommasi 1958: 12–13, pl. 2, fig. 3; 1970: 7, fig. 19. Brito 1962: 3; 1968: 7–8, pl. 4, fig. 3. Lima-Verde 1969: 10. Carrera-Rodrigues and Tommasi 1977: 81–83. Magalhães et al. 2005: 63.

Astropecten brasiliensis brasiliensis Döderlein, 1917: 83.

Astropecten armatus riensis Tommasi, 1958: 13–14, pr. 2, fig. 4. Brito 1962: 3; 1968: 8, pl. 4, fig. 2.

Astropecten riensis Tommasi, 1970: 7. Carrera-Rodrigues and Tommasi 1977: 89. Tommasi and Aron 1988: 3. Tommasi et al. 1988: 5.

Material examined. Ceará: Fortaleza, Mucuripe, 1 spec., MNRJ285, 1945. Rio Grande do Norte: Areia Branca, Ponta do Mel, 1 spec., UFPB/ECH.1919, 23.VI.182. Bahia: Salvador, 2 spec., UFBA00132, 01.III.2000.

Type locality. São Sebastião Island, São Paulo, Brazil (Clark and Downey 1992).

Description. Disk small with long, slender, dorsally flattened arms (~12.44 mm). Abactinal surface densely covered by overlapping and irregularly arranged paxillae. Paxillae with 26–30 long, blunt spinelets, the central ones sometimes shorter and more rounded than the marginal ones. Carinal paxillae larger than the adradial ones. Supromarginal plates longer (~5.7 mm) than wide (~1.19 mm), covered by short, apically rounded spinelets (giving them a granulose aspect), and having two large spines (rarely one). Inferomarginal plates with two long and flattened spines positioned vertically and forming a marginal fringe, the most ventral one being larger than the dorsal one.

Adambulacral plates with three ambulacral spines, the inner one being slightly longer than the other two. Without pedicellariae.

Colour. According to Bernasconi (1957), live animals have an intense violet colour with the spines of the marginal fringe yellowish or pinkish. Actinal surface light salmon colour. When dry specimens may be light pink or whitish.

Distribution. Honduras, Panama, Suriname, Brazil, Uruguay, and Argentina (Mar del Plata) (Tommasi 1958, 1970, Clark and Downey 1992, Alvarado et al. 2008, Ventura et al. 2007). In Brazil: CE, PE, AL, BA, RJ, SP, SC, and RS, including the islands of Fernando de Noronha and Trindade (Rathbun 1879, Verrill 1915, Tommasi 1958, 1970, Walenkamp 1976, Brito 1962, Lima-Verde 1969, Fernandes et al. 2002, Miranda et al. 2012). In this paper we establish the first record for Rio Grande do Norte. From 7 to 45 m in depth (Ventura et al. 2007).

Remarks. This species differs from the remaining species of the genus known from the Brazilian coast for presenting paxillary spinelets and spines of the marginal fringe long and thin and for having up to two spines on the supermarginal plates. The vast synonymy presented by *Astropecten brasiliensis* evidences the plasticity of some of its characters, such as the number of spines on the superomarginal plates. This character, together with the shape of the marginal spines and paxillae spinelets formed the basis for the establishment of the five known subspecies. Döderlein (1917) considered *A. armatus* Gray, 1840 and *A. erinaceus* Gray, 1840 subspecies of *A. brasiliensis* on the basis of differences in the adambulacral and superomarginal spines. Boone (1933), Clark (1940) and John (1948) disagreed with Döderlein (1917) and considered the three species not to be different, stating that the characters proposed to diagnose the species were not significant. Walenkamp (1976) listed a series of variations observed in specimens from Surinam and established *A. brasiliensis* and *A. riensis* as distinct species. Bernasconi (1957), Brito (1968) and Tommasi (1958, 1970) adopted the subspecies proposed by Müller and Troschel (1842) and Döderlein (1917) for Brazilian material. Clark and Downey (1992), analysing the neotype of the species, concluded that *A. brasiliensis* and *A. armatus* are distinct, while *A. riensis* is a synonym of the first. Furthermore, he considered all the described subspecies to be synonyms. We agree with the proposal of Clark and Downey (1992) and include the subspecies (*A. brasiliensis riensis*, *A. brasiliensis armatus*, *A. brasiliensis brasiliensis* and *A. armatus riensis*) and *A. riensis* as synonyms of *A. brasiliensis*. The specimen examined in this study was broken, but its taxonomic characters were observable, except for the loss of the superomarginal spines. Scars of these spines remained on the plates, however, and we were able to establish that two spines occurred per plate, characterizing an adult individual.

Ecological notes. As a rule burrowed in sand substrates, where it is a generalist predator, feeding on a variety of organisms from the benthic endofauna, such as bivalves, gastropods, crustaceans, echinoderms, and polychaetes (Ventura et al. 2007). As all species inhabiting soft sediments, *Astropecten brasiliensis* is suffering the impact of excessive collecting, being captured in bottom trawling nets and frequently do not resist the damage inflicted by these fishing efforts (Machado et al. 2008). Presently the species is considered to be vulnerable to extinction along the Brazilian coast.

***Astropecten cingulatus* Sladen, 1833**

Figure 5e–h

Astropecten cingulatus Sladen, 1883: 266. Brito 1962: 3; 1968: 9, pl. 4, fig. 4. Tommasi 1970: 5, fig. 16; 1985: 3. Carrera-Rodrigues and Tommasi 1977: 84–86. Tommasi and Aron 1987: 3. Manso 1989: 357. Tommasi et al. 1988: 5. Ventura et al. 2007: 231. Xavier 2010: 75.

Astropecten mesactus Studer, 1884: 46.

Astropecten jarli Madsen, 1950: 181.

Material examined. Rio de Janeiro: Cabo Frio, 1 spec., MNRJ1853, 18.VI.1997.

Type locality. Pernambuco, Brazil (Clark and Downey 1992).

Description. Body pentagonal, flattened dorso-ventrally. Five long (~37.70 mm) and narrow (~9.56 mm) arms (length of arm corresponds to approximately four times its width) (Fig. 5e). Madreporite oval (~1.52 mm) and marginal. Epiproctal cone pronounced. Paxillae small and granulose, with 1–4 central spinelets and 9–12 marginal spinelets. Paxillar spinelets granulose (Fig. 5e). Superomarginal plates granulose (Fig. 5g). Two fringes of marginal spines aligned horizontally. First row of spines of inferomarginal plates with three marginal spines, disposed in parallel to each other, two being of the same length and one shorter. Second row with four elongate and slightly flattened spines, three of which are subequal in length and one much shorter. Oral spines short, forming a bundle at the apex of the jaw (Fig. 5f). Adambulacral plates with 3–4 divergent spines, the median one being the largest (Fig. 5h). Subambulacral spines forming a bundle of elongate and slightly flattened (lanceolate) spines. Pedicellariae rarely present.

Colour. According to Benavides-Serrato et al. (2011) and Bernasconi (1957), the species has the abactinal surface red or orange-red and the actinal surface white. Ventura et al. (2007) recorded a cream-colour on the dorsal surface and white on the oral surface in Brazilian specimens.

Distribution. North Carolina, the Bahamas, Gulf of Mexico, Mexico, Nicaragua, Costa Rica, Panama, Colombia, Brazil, Uruguay, Argentina, and Africa (Tommasi 1970, Carrera-Rodríguez and Tommasi 1977, Clark and Downey 1992, Ventura et al. 2007, Alvarado et al. 2008). In Brazil: PE, RJ, SP, and SC, including the submarine banks and mountain ranges Vitória-Trindade and Vitória Island (SP) (Brito 1962, Tommasi 1970, 1985, Tommasi and Aron 1987, Manso 1989, Xavier 2010). Intertidal to 1350 m in depth (Clark and Downey 1992), being most frequent between 51 and 129 m (Carrera-Rodríguez and Tommasi 1977).

Remarks. *Astropecten cingulatus* differs from its closest species, *A. articulatus*, for having three rounded spines on each inferomarginal plate, and for having subambulacral spines that are smaller than the adambulacral spines and rounded. Bernasconi (1957) stresses a few morphological variations observed in specimens from Uruguay and Argentina. Among these are the aspect of the superomarginal plates, which do not have large spines, or then there are only a few small, granuliform spines on the first plates. According to Ventura et al. (2007) the specimens collected along the Brazilian

coast have short arms, in contrast to the indication in the original diagnosis. The single individual we examined, on the other hand, corresponds to that indicated in the literature (length about four times its width).

Ecological notes. This species lives on sandy or muddy bottoms of the littoral region up to depths of 50 m (Tommasi 1970, Machado et al. 2008). It feeds mainly on gastropods, bivalves, crustaceans, and cirripeds (Ventura et al. 2007). *Astropecten cingulatus*, and other species of the genus, are frequently captured in trawling nets and the species is presently included among those vulnerable to extinction in Brazil (Machado et al. 2008). According to Brito (1962), this species is abundant along the coast of Pernambuco, but no other works conducted in this state confirm this observation.

Astropecten marginatus Gray, 1840

Figures 6a–e, 12b

Astropecten marginatus Gray, 1840: 181. Tommasi 1958: 14, pl. 2, fig. 5; 1970: 5, fig. 15. Brito 1962: 3; 1968: 7, pl. 4, fig. 1. Lima-Verde 1969: 11. Carrera-Rodrigues and Tommasi 1977: 88–89. Tommasi et al. 1988: 5. Nomura and Fausto Filho 1966: 19. Gondim et al. 2008: 155. Lima and Fernandes 2009: 58. Xavier 2010: 75.

Astropecten ciliatus Grube, 1857: 340.

Astropecten richardi Gary, 1840: 181.

Astropecten orans Sluiter, 1895: 54.

Material examined. Rio Grande do Norte: Areia Branca, Ponta do Mel, 2 spec., UFPB/ECH.1842, 23.VI.1982. Paraíba: Cabedelo, Miramar Beach, 1 spec., UFPB/ECH.1840, 03.II.1983; João Pessoa, 7°7'23,3"S; 34°48'27,9"W, 1 spec., UFPB/ECH.1839, 14.IX.1980; João Pessoa, Tambaú Beach, 1 spec., UFPB/ECH.864, 03.X.2007. Pernambuco: Goiana, Catuama, UFPB/ECH.1427, 1 spec., 31.X.1982.

Type locality. Unknown (Clark and Downey 1992).

Description. Body flattened. Five broad, triangular arms (Fig. 6a, b). Abactinal surface covered by paxillae arranged in regular transversal rows. Circular madreporite positioned marginally in one of the abactinal intermediate areas. Carinal paxillae slightly smaller than the adradials (Fig. 6d). Paxillae small with 6–8 central spinelets and 12 marginal spinelets, all short and blunts. Superomarginal plates granulose, broader (~3.89 mm) than long (~2.00 mm) (Fig. 6c, d). Inferomarginal plates granulose, with two thick, blunt, parallel spines of similar length (~3.92 mm) and one small spine positioned laterally in relation to the other two. These spines form a well defined marginal bundle. Actinal surface with inferomarginal plates partially naked, having two series of marginal spines positioned laterally and one other marginal series with four thin, elongate, and flattened spines (~1.66 mm), located behind the aboral marginal row of spines (Fig. 6e). Adambulacral plates with a series of small spines on the proximal face and three long, narrow, and flattened adambulacral spines, the median

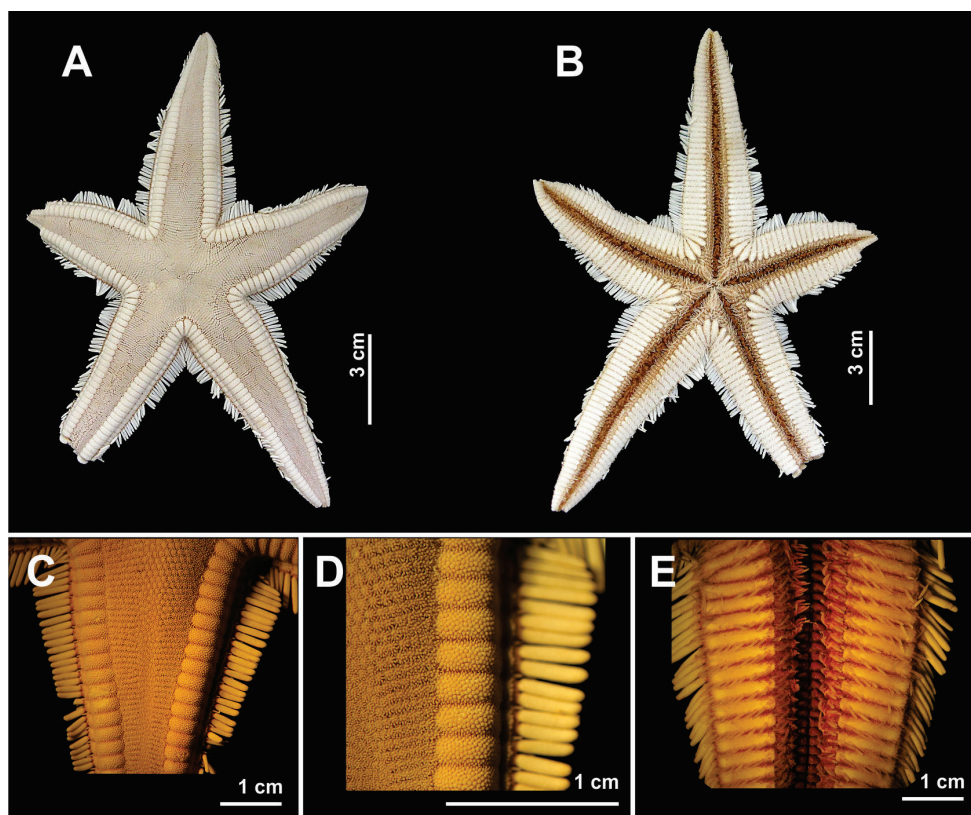


Figure 6. Some species of the family Astropectinidae recorded in northeastern Brazil. *Astropecten marginatus* (A–E) **A** Abactinal view **B** Actinal view **C** Abactinal view of the arm **D** Detail of the superomarginal plate, and **E** Actinal view of the arm.

of which is longest and widest. Six elongate, narrow, and pointed oral spines (~1.67 mm). Ocular plate small and bilobed.

Colour. Dorsally either blue with white margins (Clark and Downey 1992) or uniformly orange-coloured (Benavides-Serrato et al. 2011). Most specimens collected in northeastern Brazil vary from cream-coloured to grayish. Dried specimens become white.

Distribution. Costa Rica, Puerto Rico, Colombia, Venezuela, Guyana, and Brazil (Tommasi 1958, Clark and Downey 1992, Hendler et al. 1995, Alvarado et al. 2008, Benavides-Serrato et al. 2005, 2011). In Brazil: CE, PB, PE, RJ, SP, SC, and RS (Bernasconi 1955, Brito 1962, Lima-Verde 1969, Netto 2006, Gondim et al. 2008, Lima and Fernandes 2009, Xavier 2010). This is the first record for the littoral of Rio Grande do Norte. From 1 to 130 m in depth (Clark and Downey 1992).

Remarks. *Astropecten marginatus* differs from the remaining species of the genus known from Brazil for having large, triangular arms and two long, thick and blunt spines on each inferomarginal plate. Unlike other species of *Astropecten*, *A. marginatus*

shows little morphological variation in characters considered of taxonomic interest (Walenkamp 1976). We observed both juveniles ($R = 11.73$ mm) and adults ($R = 81.41$ mm).

Ecological notes. This species lives in substrates containing sand or sand with mud (Ortega et al. 2010). As most species of the genus, it is an active predator with a generalist food diet (Ortega et al. 2010). This is one of the most common species in northeastern Brazil, being abundant below 2–4 m (Benavides-Serrato et al. 2011). Together with other species in the genus, populations of *A. marginatus* suffer great collecting pressures from bottom trawling fishing nets. Presently it is included among the Brazilian species vulnerable to extinction (Machado et al. 2008).

Order Valvatida Perrier, 1884

Family Asterinidae Gray, 1840

Asterinides folium (Lütken, 1860)

Figure 7a–e

Asterina minuta Gray, 1840: 289.

Asteriscus folium Lütken, 1860: 60–61.

Asterina folium A. Agassiz, 1877: 106, pl. 14, figs 7–9.

Asterinides folium Verrill, 1913: 479; Brito 1962: 3; 1968: 17, pl. 7, figs 2–3; 1971: 262. Tommasi 1970: 15, fig. 38. Oliveira et al. 2010: 3, fig. 2a.

Material examined. Paraíba: 06°59'S; 34°47'W, 1spec., UFPB/ECH.572, 07.III.2006, 10m. Bahia: Camaçari, Guarajuba, Busca Vida Beach, 1spec., UFBA00685, 01.II.2006; 2spec., UFBA00983, I.2010, 23m; 1spec., UFBA01163, VII.2010, 25m; 2spec., UFBA01107, I.2010, 23m; Salvador, Todos os Santos Bay, 1spec., UFBA01107, 05.IV. 1997, 12m; Salvador: Itapuá, 12°57'28"S; 38°21'22"W, 1spec., UFBA00528, 19.XI.2007, 1m.

Type locality. Saint Thomas, Virgin Islands (O'Loughlin 2002).

Description. Body inflated, pentagonal (Fig. 7a, b). Five short arms (some specimens may have 4–6 arms). Abactinal plates imbricated, decreasing in size towards the margin of the body, with 2–4 short, hyaline, divergent spines, which have the extremity trifurcate (Fig. 7c). Between each of these plates there is a papula (Fig. 7c). Anus located in the center of the abactinal surface. Superomarginal plates similar to the remaining abactinal plates, but with more numerous and slightly longer spines, forming a dense bundle (Fig. 7a). Papulae restricted to the abactinal surface. Actinal plates similar to the abactinal plates, but a little bigger and longer, having 1–3 divergent spines, also similar to the dorsal ones, but slightly longer (Fig. 7b). Inferomarginal plates similar to the remaining actinal plates. Adambulacral plates with three thin, vitreous, elongate spines (~ 0.035 mm), having the tips trifurcate (Fig. 7d). Six thin, vitreous, elongate oral spines (~ 0.43 mm) (Fig. 7e).

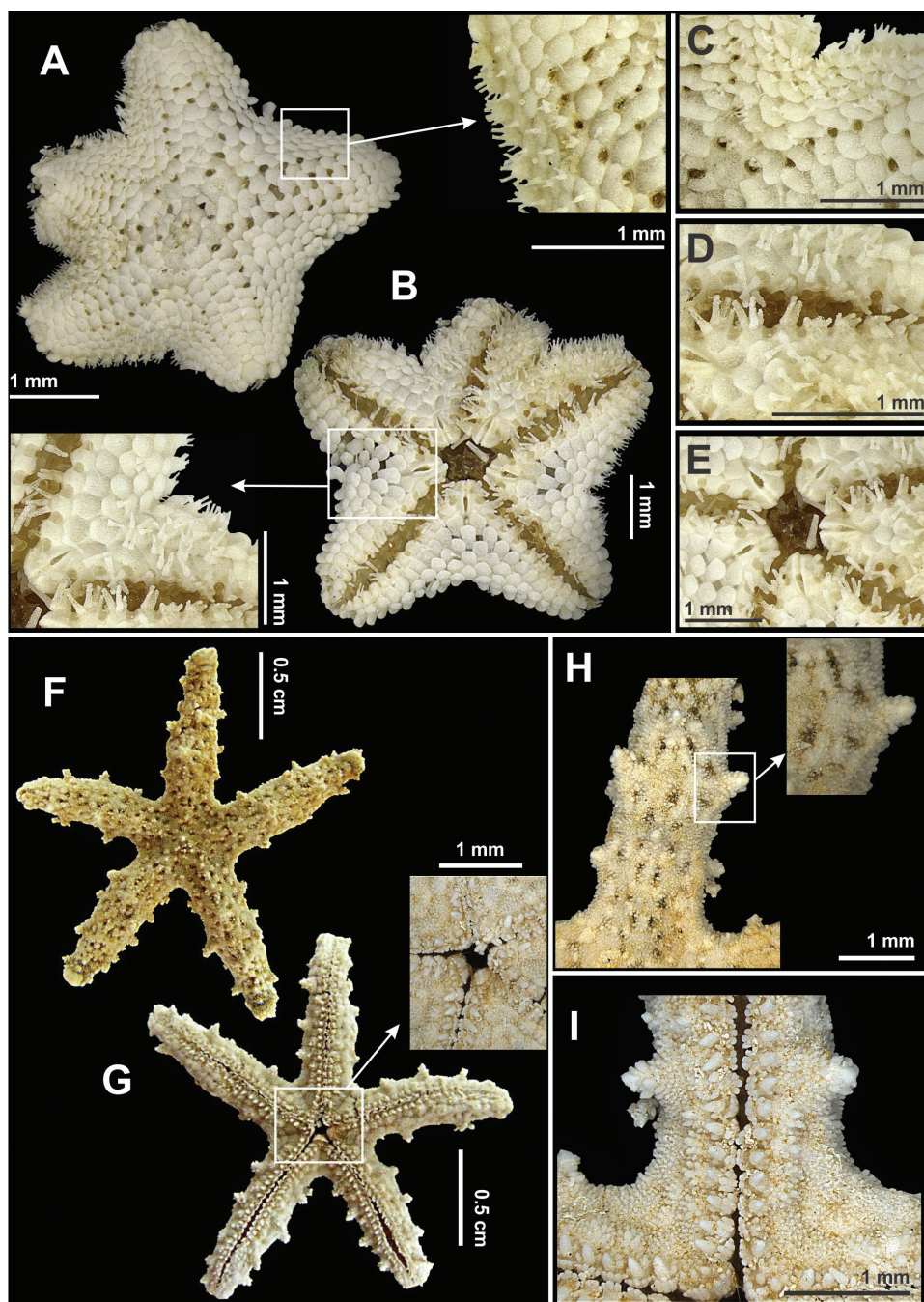


Figure 7. Some species of the order Valvatida recorded in northeastern Brazil. *Asterinides folium* (A–E) **A** Abactinal view, in detail the superomarginal plates **B** Actinal view, in detail actinal internidate area **C** Detail the abactinal intermediate are **D** Actinal view of the arm **E** Detail of the mouth; *Mithrodia clavigera* (F–I) **F** Abactinal view **G** Actinal view, in detail the mouth **H** Abactinal view of the arm, in detail a spine, and **I** Actinal view of the arm.

Colour. Juvenile specimens vary from white to cream-coloured, larger juveniles are yellow to reddish, while adults are blue or greenish-blue (Hendler et al. 1995). Brito (1968) recorded a dark grayish-blue for 25 specimens from Trindade Island (ES).

Distribution. Bermudas, Florida, Bahamas, Belize, Panama, and Brazil (Verrill 1915, Clark and Downey 1992, Hendler et al. 1995, Alvarado et al. 2008, Benavides-Serrato et al. 2011). In Brazil: BA, RJ, and Trindade Island (Brito 1962, 1968, 1971, Oliveira et al. 2010). In the presente study we record for the first time its presence in the State of Paraíba. Intertidal to 15 m in depth (Hendler et al. 1995).

Remarks. Only two species of the genus *Asterinides* are known from the Atlantic Ocean, *A. folium* and *A. hartmeyer*i (Döderlein, 1910). The first is recorded for Bermudas and southern Brazil and the second only for the Caribbean region. According to Clark and Downey (1992) these species are partially sympatric, and for this reason have previously easily been confused with each other. In a revision of family Asterinidae based on molecular and morphological data, O’Loughlin and Waters (2004) transferred *A. folium* and *A. hartmeyer*i from the genus *Asterina* to the genus *Asterinides*, remarking on the morphological similarities between these two species. *Asterinides folium* differs from *A. hartmeyer*i for having bigger papular pores, 6 to 7 series of actinal plates and abactinal plates arranged into two rows. A broad discussion of the main differences between these two species is given by Clark and Downey (1992). According to Hendler et al. (1995), this species rarely reaches 2.5 cm in diameter. Specimens examined in this study had a larger ray (R, maximum of 7.76 mm) and differed from those described by Hendler (op cit.) for not having narrow radial areas inflated, having instead the abactinal surface completely inflated.

Ecological notes. This species lives in association with coral reefs, being found particularly under rocks or corals of the reef flat (Hendler et al. 1995). The specimen from Paraíba recorded in this study was found associated with rhodolite beds at 10 m depth. Although the species is reported from several localities, is has never been found in large numbers (Hendler et al. 1995, Benavides-Serrato et al. 2011). Only Brito (1971) observed this species to be relatively abundant mainly under rocks at Trindade Island.

Family Mithrodiidae Viguiet, 1878

Mithrodia clavigera (Lamarck, 1816)

Figure 7f–i

Asterias clavigera Lamarck, 1816: 562.

Mithrodia clavigera Verrill, 1870: 289.

Mithrodia spinulosa Gray, 1840: 288.

Ophidiaster echinulatus Müller & Troschel, 1842: 32.

Echinaster echinulatus von Martens, 1866: 59.

Mithrodia clavigera Perrier, 1875: 378.

Mithrodia victoriae Bell, 1882: 123, pl. 6, fig. 2. Brito 1962: 3; 1968: 16. Tommasi 1970: 19, fig. 55.

Material examined. Paraíba: 7°04'S; 34°41'W, 1 spec., UFPB.ECH.880, 17.II.1981, 26m.

Type locality. Unknown (Clark and Downey 1992).

Description. Disk small (Fig. 7f). Five cylindrical and narrow arms (~2.52 mm) (Fig. 7f, g). Abactinal and actinal surfaces granulose (Fig. 7h). Skeleton formed by polygonal primary plates (usually hexagonal) that are widely spaced and united by secondary plates of rectangular shape, forming a reticulum. Some carinal and adradial plates with a long, narrow, and blunt spine (~0.77 mm). Papula large and single, found between the abactinal plates. Papulae restricted to abactinal surface. Granules covering body and spines small and with spinous tip. Granules from base of spines larger than at other localities. One conical and elongate subambulacral spine (~0.32 mm), forming a well defined row at base of ambulacral groove (Fig. 7i). Four slightly flattened adambulacral spines, the median ones being the largest. Eight short and rectangular oral spines, of which the median ones are largest (Fig. 7g).

Colour. Arms banded with dark brown or red lines, unusually green (Clark and Downey 1992). Specimens preserved in alcohol become uniformly white.

Distribution. Mexico, Cuba, Nicaragua, Brazil, Indo-Pacific (except Hawaii) (Hayashi 1940, Abreu-Pérez et al. 2005, Alvarado et al. 2008). In Brazil: ES (Vitória Banks) (Brito 1968, Clark and Downey 1992). In this study we provide the first record for northeastern Brazil. From 24 to 71m in depth (Clark and Downey 1992).

Remarks. *Mithrodia clavigera* is the only species of the family Mithrodiidae recorded for the Western Atlantic. For some time, two species were considered present: *M. clavigera* and *M. victoriae*. The later species was described by Bell (1882), based on two small specimens from submerged banks of Vitória (Victoria Bank) (Espírito Santo, Brazil). Since its description the validity of *M. victoriae* was questioned, and the distinction between these two species was discussed by Engel et al. (1948) and Pope and Rowe (1977). These authors concluded that the species should be synonymized but, due to the lack of material, this action was not formally carried out. Clark and Downey (1992) analysed a large number of individuals of several sizes and agreed with the observations of Engel et al. (op. cit.) and Pope and Rowe (op. cit.), considering the two species to be synonyms. The individual we analysed is juvenile (R = 9.80 mm) and corresponds to the characterization of juvenile specimens by Engel et al. (1948). These authors provide details on the aspect of the pedicellariae of *Mithrodia clavigera*, but pedicellariae were not found in our specimen.

Ecological notes. This species lives on hard substrates covered by incrusting organisms and in reef gravel (Abreu-Pérez et al. 2005). For Paraíba it was recorded associated with rhodolith banks. According to Guille et al. (1986) this species is more active during the night.

Family Oreasteridae Fisher, 1911

Oreaster reticulatus (Linnaeus, 1758)

Figure 8a–g, 12c

Asterias gigas Linnaeus, 1753: 114.

Asterias reticulata Linnaeus, 1758: 661.

Pentaceros reticulatus Gray, 1840: 276.

Oreaster reticulatus Linnaeus, 1758. Tommasi 1958: 16–17, pl. 3, fig. 2; 1970: 10–11, fig. 31. Brito 1962: 3; 1968: 5–6, pl. 2, figs 1–3. Lima-Verde 1969: 11. Fernandes et al. 2002: 422. Magalhães et al. 2005: 63. Ventura et al. 2007: 238. Manso et al. 2008: 185, fig. 8c, d, e. Xavier 2010: 75. Alves et al. 2010: 757. Miranda et al. 2012: 143, 144.

Oreaster aculeatus Müller & Troschel, 1842: 50.

Oreaster lapidarius Grube, 1857: 342.

Oreaster tuberosus Möbius, 1859: 6.

Oreaster gigas Lütken, 1860: 64–75.

Oreaster reticulatus var. *bermudensis* H.L. Clark, 1942: 372, figs 1–2.

Material examined. Ceará: off Fortaleza, 1spec., UFPB/ECH.1255, Geomar XXIV, V.1985. Paraíba: 1spec., UFPB/ECH.1579, 26.X.1980; Cabedelo, Farol de Cabedelo Reef, UFPB/ECH.1254, 22.I.1981, 26m; 1spec., UFPB/ECH.1588, 26.X.1980; 6°39'S; 34°49'W, 1spec., UFPB/ECH.1575, 28.V.1981, 20m; 6°39'5"S; 34°46'W, 1spec., UFPB/ECH.1429, 1spec., 29.V.1981, 35m; 6°39'05"S; 34°49'W, 1spec., UFPB/ECH.1251, 28.V.1981, 20m; 6°39'05"S; 34°49'W, 1spec., UFPB/ECH.1578, 28.V.1981, 20m; 6°50'S; 34°47'W, 1spec., UFPB/ECH.1253, 11.V.1981, 18m; 6°52'S; 34°46'W, 1spec., UFPB/ECH.1872, 19.II.1981, 18m; 6°52'S; 34°48'W, 1spec., UFPB/ECH.1590, 04.II.1981, 10m; 6°52'S; 34°49'W, 1spec., UFPB/ECH.1593, 04.II.1981, 12m; 6°57'S; 34°41'W, 1spec., UFPB/ECH.1577, 12.II.1981, 26m; 7°01'S; 34°47'05"W, 2spec., UFPB/ECH.1252, 02.V.1981, 11m; 7°04'S; 34°41'W, 2spec., UFPB/ECH.1576, 17.II.1981, 22m; 07°04'24,4"S; 034°47'49"W, 1spec., UFPB/ECH.1871, 24.VI.2005, 6m; 7°07'S; 34°47'W, 1spec., UFPB/ECH.1430, 05.II.1981, 10m; 7°10'S; 34°38'W, 1spec., UFPB/ECH.1873, 26.03.1981, 25m; 7°13'S; 34°42'W, 1spec., UFPB/ECH.1574, 27.III.1981, 10m; 7°34'S; 34°39'W, 1spec., UFPB/ECH.1594, 1spec., 7°34'S; 34°39'W, Paraíba, 22.I.1981, 26m. Pernambuco: Itamaracá Island, 4spec., UFPB/ECH.1581, VIII.1980, 20m; Suape Beach, 1spec., UFPB/ECH.1580, I.1980.

Type locality. 'Las Antillas Occidentales' or 'Spanish West Indies' (Clark and Downey 1992).

Description. Body pentagonal. Disk high, inflated, concave on actinal side (Fig. 8a, b). Five short arms (Fig. 8a). Abactinal plates with one thick, short, blunt spine (~2.43 mm). Among these plates there occur papular areas, which are covered by small granules and bivalve pedicellariae (Fig. 8c). These granules cover the entire body, including the bases of the spines. Superomarginal plates with one short, thick and blunt spine (~3.38 mm), determining the margin of the body. Inferomarginal plates similar to superomarginal plates, with one or two small and thick spines. Papular areas restricted to abactinal

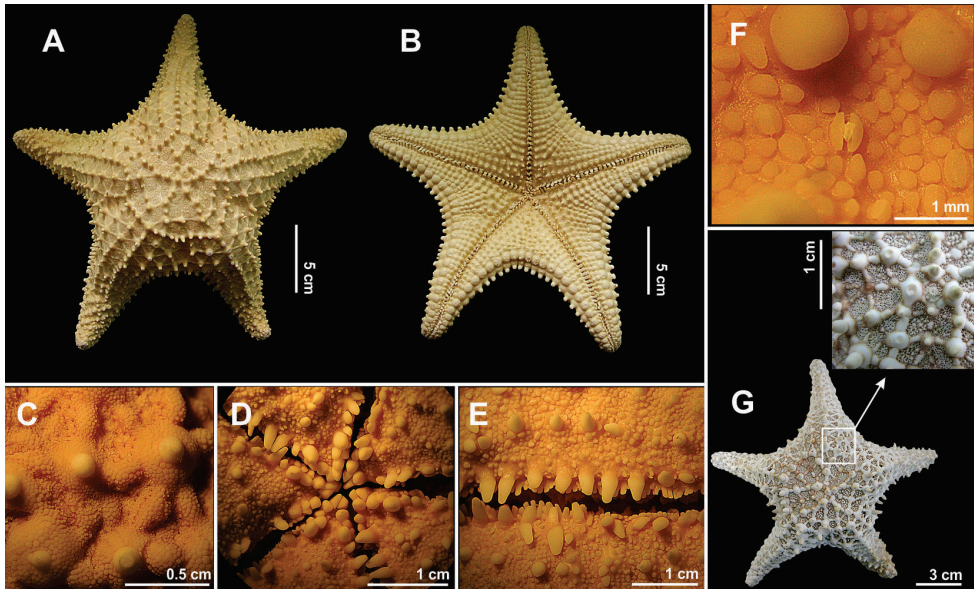


Figure 8. Some species of the order Valvatida recorded in northeastern Brazil. *Oreaster reticulatus* (A–G) **A** Abactinal view **B** Actinal view **C** Detail view da abactinal surface **D** Detail of the mouth **E** Actinal view of the arm **F** Detail of the bivalve pedicellariae, and **G** Skeleton, in detail its arrangement into a reticulum.

surface. Actinal surface granulate, with a great number of pedicellariae, especially in areas near the mouth and abulacral groove. Actinal plates with 1–2 short, conical, and blunt spines (~1.53 mm). Ambulacral plates with 5–6 short and flattened spines, of which the median spines are the largest (Fig. 8e). Short, conical, spines (~3.16 mm) form a well defined row of spines on the margins of the ambulacral grooves. Four short, thick, blunt oral spines (Fig. 8d). Sessile bivalve pedicellariae distributed over entire body of animal (Fig. 8f). Skeleton formed by conical, abactinal plates interconnected by secondarily elongated and widened plates, arranged into a reticulum (Fig. 8g).

Colour. According to Hendler et al. (1995) and Verrill (1915) the colour pattern of this species is very variable, even among individuals from a same population. Along the Brazilian coast the most common colour is orange or brownish red. Yet juvenile individuals differ significantly from adults. According to Benavides-Serrato et al. (2011) and Hendler et al. (1995) the aboral surface of juveniles is frequently olive-green and usually presents green-grey or coffee-coloured spots. In the adults, on the other hand, this colour is orange with lighter or darker tubercles on the disk and arms. The oral surface in both stages is beige or cream-coloured.

Distribution. North and South Carolina, the Bermudas, the Bahamas, Belize, Guatemala, Honduras, Cuba, Nicaragua, Costa Rica, Venezuela, Brazil, and Cabo Verde (Tommasi 1970, Walenkamp 1976, Hendler et al. 1995, Ventura et al. 2007, Alvarado et al. 2008, del Valle García et al. 2008). In Brazil: MA, CE, PB, PE, AL, BA, RJ, SP, and SC, including Abrolhos and Trindade Island (Rathbun 1879, Verrill 1915, Clark 1942, Tommasi 1958, 1970, Brito 1962, 1968, Lima-Verde 1969, Fernandes et al.

2002, Magalhães et al. 2005, Xavier 2010, Miranda et al. 2012). In this study we record the species for the first time in the States of Rio Grande do Norte, and Alagoas. From 0 to 800 m in depth, being most abundant up to 50 m.

Remarks. Only two species of the genus *Oreaster* are known for the Atlantic Ocean, *Oreaster clavatus* and *O. reticulatus*. The first is known only from the Island of Cape Verde, São Thomé and the Gulf of Guinea. The second, occurs widely throughout the West Atlantic, from North Carolina to the south of Brazil (Clark and Downey 1992), its known southern limit being located in the State of Santa Catarina. *Oreaster reticulatus* differs from its congeneric *O. clavatus* for presenting an inflated body and abactinal plates with tubercles or spines. Clark (1942) described the variety *O. reticulatus* var. *bermudensis* on the basis of the irregular placement of spines and papulae on the abactinal surface and of the presence of only one spine on the actinal plates. However, these characters also occur in other specimens from the Atlantic and thus do not sustain the name. According to Hendler et al. (1995) the species may attain a disk diameter of up to 500 mm. We observed morphological variations in both juveniles and adults, but were not able to correlate these with colour patterns in this preserved material.

Ecological notes. The species lives in shallow reef environments with calm water, coastal lagoons, seagrass beds (*Thalassia*, *Halodule* and *Syringodium*), and mangrove channels (Benavides-Serrato et al. 2011). In this study the species was recorded in rhodolite beds and coastal reefs below 6 m. According to Verrill (1915) *Oreaster reticulatus* was the most abundant species in the States of Bahia and Pernambuco. Presently it is difficult to find along the northeastern coast of Brazil, and is listed as vulnerable to extinction (Machado et al. 2008). This is an omnivorous species, feeding mainly on microorganisms from organic matter associated with the sand of seagrass beds and algal substrates. However, it is also an opportunistic predator of echinoderms, such as *Tripneustes ventricosus* (Lamarck, 1816) and *Meoma ventricosa ventricosa* (Lamarck, 1816), as well as of individuals belonging to its own species and to a large variety of sponges (Hendler et al. 1995). The only known predator of adults belonging to this species is the gastropod *Charonia variegata* (Lamarck, 1816), while young individuals are known to be eaten by a great variety of fishes (Scheibling 1980).

Order Velatida Perrier, 1884

Family Pterasteridae Perrier, 1875

Calyptraster coa Sladen, 1882

Figure 9a–h

Calyptraster coa Sladen, 1882: 207. Tommasi 1970: 13.

Calyptraster personatus Madsen, 1947: 3–7, figs 1–2.

Material examined. MZUSP (without registration number), 1spec., W Besnardi, dredging 5142. MZUSP (without registration number), 2spec., W Besnardi, dredging 5363.

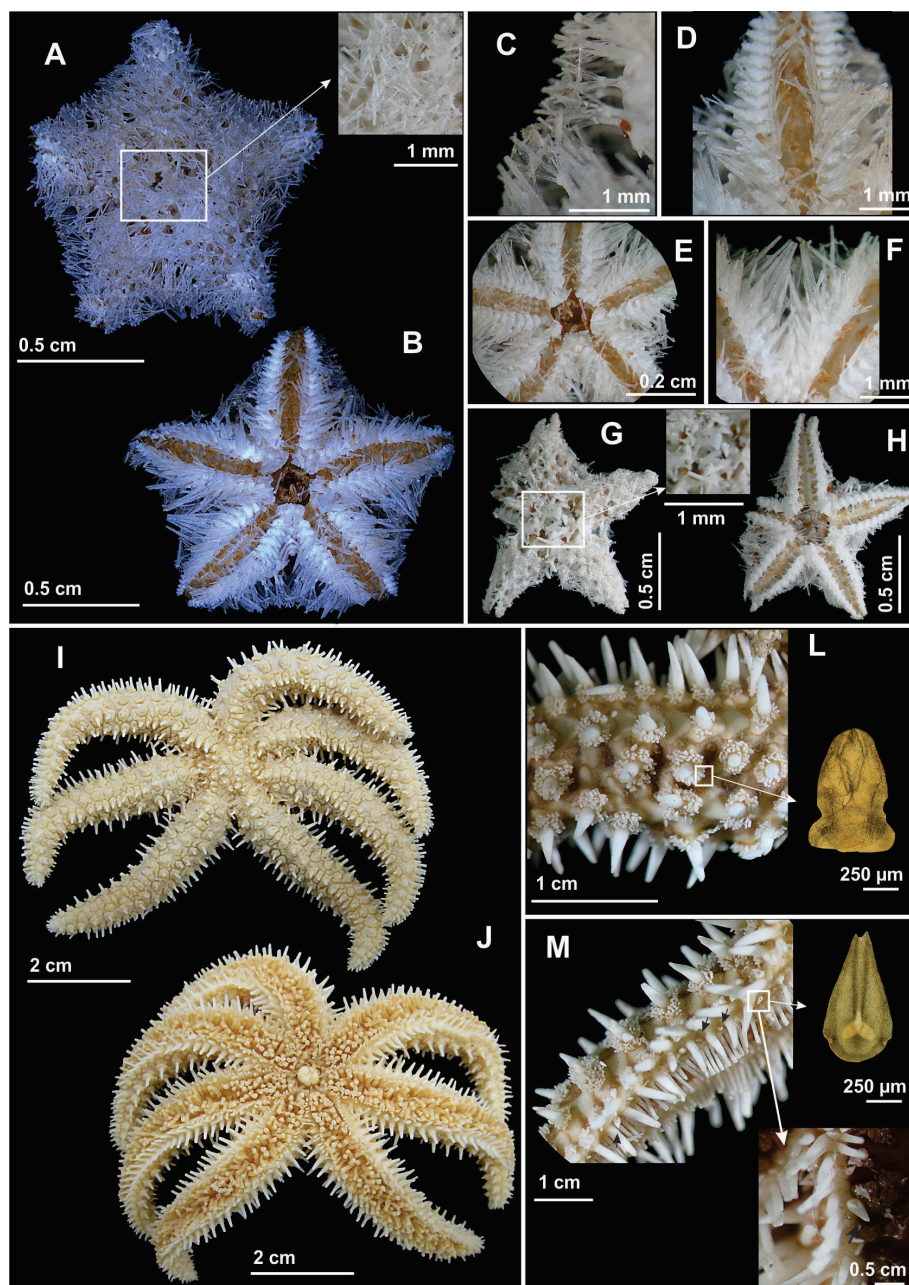


Figure 9. Some species of the order Velatida (A–H) and Forcipulatida (I–M) recorded in northeastern Brazil. *Calyptraster coa* (A–H) **A** Abactinal view, in detail the supradsorsal membrane **B** Actinal view **C** Detail of the paxillae with long peduncles **D** Actinal view of the arm **E** Detail of the mouth **F** Detail of the actinal intermediate area **G** Abactinal view, in detail oscular valves **H** Actinal view; *Coscinasterias tenuispina* (I–M) **I** Abactinal view **J** Actinal view **L** Abactinal view of the arm, in detail the bivalve pedicellariae (optical microscopic image), and **M** Lateral view of the arms, in detail the bivalve pedicellariae (optical microscopic image).

Type locality. Recife, Pernambuco, Brazil (Clark and Downey 1992).

Description. Body pentagonal (Fig. 9a, b, g, h). Five short arms. Supradorsal membrane thin and transparent (Fig. 9a). Spiracles moderately large, numerous, irregularly distributed. Oscule large, surrounded by long oscular valves with an enlarged extremity (Fig. 9g). Abactinal surface with paxillae. Paxillae with long peduncles and a crown of 5 to 6 long and vitreous spinelets (Fig. 9c). Skeletal plates narrow, long and vitreous, forming a reticulum. Actinal surface slightly concave. Oral spines long and vitreous, the lateral ones being longer and thicker (Fig. 9e). Adambulacral plates with three or four spines (Fig. 9d).

Colour. From light brown to hey-coloured (Sladen 1889).

Distribution. The Bahamas, Florida, and Brazil (Clark and Downey 1992). In Brazil: PE (Tommasi 1970; Clark and Downey 1992). From 260 to 933 m in depth (Clark and Downey 1992).

Remarks. The genus *Calyptaster* presently contains five species (Mah 2013), four of which occur in the Western Atlantic: *C. coa*, *C. personatus* (Perrier, 1885), *C. tenuissimus* Bernasconi, 1966 and *C. vitreus* Bernasconi, 1972. The first two have a similar geographical distribution, occurring from the Bahamas to Brazil and Colombia, respectively, while the last two are restricted to the coast of Argentina. According to Clark and Downey (1992), this genus is problematic, and the distinctions between *C. coa* and *C. personatus* remain to be better established. Walenkamp (1979) provides good descriptions and discusses the main morphological differences between these species. In the phylogenetic analysis of the family Pterasteridae by Villier et al. (2004), it is concluded that *Calyptaster* represents a monophyletic genus. *Calyptaster coa* differs from *C. personatus* for having conical suboral spines, an osculum surrounded by valves with enlarged extremities, and for being distributed no deeper than 1000 m. Specimens observed in this study were all juveniles. Smaller specimens tend to have longer arms and a more flattened body. Our material was badly preserved in general, not permitting a detailed description of their morphological characters.

Ecological notes. This species is quite rare, from deep waters, with little known of its biology and ecology. The species was collected in bottoms containing red mud (Sladen 1889).

Family Ophidiasteridae Verril, 1870

Linckia guildingi Gray, 1840

Figure 10a–e, 12d

Linckia guildingii Gray, 1840: 285. Tommasi 1958: 17. Brito 1962: 3; 1968: 4–5, pl. 1, fig. 3; 1971: 262. Lima-Verde 1969: 11. Tommasi and Aron 1988: 3. Tommasi et al. 1988: 6. Fernandes et al. 2002: 422. Gondim et al. 2008: 154.

Linckia pacifica Gray, 1840: 285.

Ophidiaster ornithopus Müller & Troschel, 1842: 31

Ophidiaster ehrenbergi Müller & Troschel, 1842: 31

Linckia ornithopus Verrill, 1867: 344.

Linckia nicobarica Lütken, 1872: 265.

Linckia ehrenbergi Lorient, 1885: 31.

Linckia guildingi Verrill, 1907: 325. Miranda et al. 2012: 144.

Material examined. Paraíba: 6°29'S; 34°48'W, 1spec., UFPB/ECH.1235, 04.VI.1981, 30m; 6°29'S; 34°51'W, 1spec., UFPB/ECH.1244, 05.VI.1981, 22m; 6°33'S; 34°51'W, 1spec., UFPB/ECH.1243, 04.VI.1981, 20m; 7°01'S; 34°30'W, 1spec., UFPB/ECH.1856, 13.II.1981, 26m; 7°01'S; 34°30'W, 3spec., UFPB/ECH.1238, 13.II.1981, 26m; 7°04'S; 34°44'W, 1spec., UFPB/ECH.1237, 16.II.1981, 16m; 7°12'5"S; 34°36'W, 1spec., UFPB/ECH.1241, 01.IV.1981, 26m; 7°28'S; 34°34'W, 1spec., UFPB/ECH.1242, 06.V.1981, 30m; João Pessoa, Cabo Branco Beach, 1spec., UFPB/ECH.1159, 19.II.2003. 1spec., UFPB/ECH.1160, 04.XI.2006, 1spec., UFPB/ECH.1161, 06.X.1979; 3spec., UFPB/ECH.1236, 25.X.2007, 1spec., UFPB/ECH.1245, 16.V.2007, 1spec., UFPB/ECH.1246, 19.IV.2005; 1spec., UFPB/ECH.1247, 08.IX.2006, 2spec., UFPB/ECH.1248, 25.X.2007, 1spec., UFPB/ECH.1250, 03.VII.2004, 1spec., UFPB/ECH.1479, 13.XI.2008, 1spec., UFPB/ECH.1502, 08.II.2009, 1spec., UFPB/ECH.1867, III.2007. Pernambuco: Paulista, Pau Amarelo reef, 1spec., UFPB/ECH.1845, 08.XI.1982. Alagoas: Paripueira, Paripueira Beach, 2spec., UFPB/ECH.1851, 01.II.1983; Maceió, Ponta Verde Beach, 1spec., UFSITAB-199, I.2007, 1spec., UFSITAB-200, I.2007; Marechal Deodoro, Francês Beach, 5spec., UFPB/ECH.1855, 29.I.1983, 2spec., UFPB/ECH.1847, 20.XII.1984, 1spec., UFPB/ECH.1849, 19.II.1985, 2spec., UFPB/ECH.1857, 19.II.2011. Bahia: Salvador, Itapoã Beach, 1spec., UFPB/ECH.1848, 21.XII.1984; Itaparica, Pedrao, 4spec., UFPB/ECH.1853, 18.IX.1982; Itaparica, Barra Grande, 1spec., UFPB/ECH.1854, 17.IX.1982; Santa Cruz da Cabralia, Ponta da Coroa Vermelha, 5spec., UFPB/ECH.1846, 15.X.1982; Santa Cruz da Cabralia, Ponta do Mutá reef, 5spec., UFPB/ECH.1850, 16.X.1982; Porto Seguro, Ponta Grande reef, 5spec., UFPB/ECH.1852, 15.X.1982.

Type-locality. Saint Vincent, West Indies (Clark and Downey 1992).

Description. Disk small. From four to six long, thin, cylindrical arms (Fig. 10a, b). Abactinal and actinal surfaces granuliform. Two or more madreporites. Abactinal plates rounded, inflated, irregularly arranged. Among these plates there are papular areas with 5–23 pores (Fig. 10c). Papular areas restricted to abactinal surface. Superomarginal and inferomarginal plates similar and uniform in size, separated by a row of papular areas. Actinal plates forming 2–3 series, which extend to the tip of the arms and are covered by granules a little larger than those on abactinal surface. Ambulacral plates with two short, blunt, parallel spines, one being much larger than the other (Fig. 10d). Behind these there is one wide, thick, blunt, ambulacral spine. Oral spines slightly longer (~0.68 mm) than remaining spines, having their tips rounded (Fig. 10e). Ocular plates also granulose.

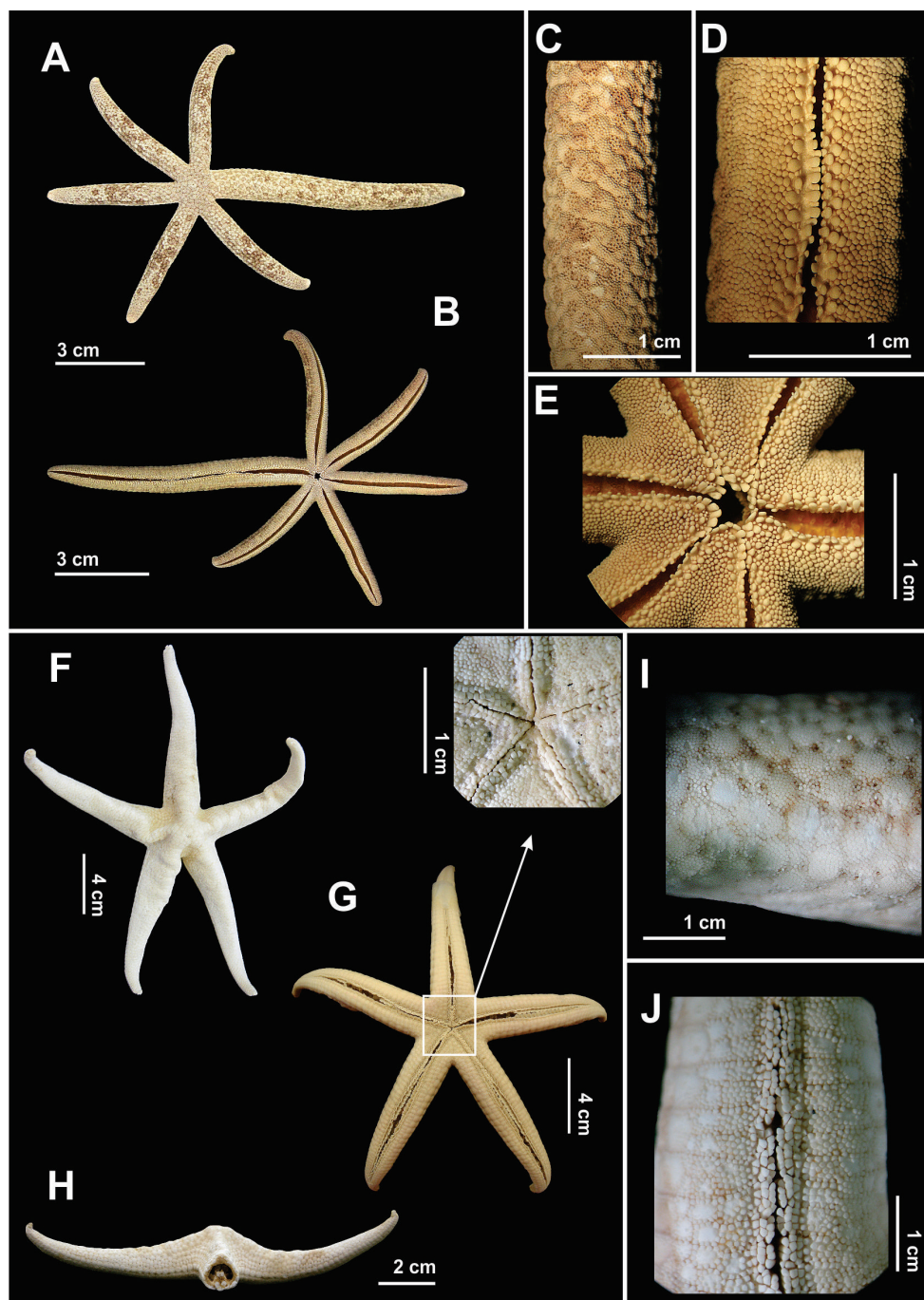


Figure 10. Some species of the order Velatida recorded in northeastern Brazil. *Linckia guildingi* (A–E) **A** Abactinal view **B** Actinal view **C** Abactinal view of the arm **D** Actinal view of the arm **E** Detail of the mouth; *Narcisia trigonaria* (F–J) **F** Abactinal view **G** Actinal view, in detail the mouth **H** Lateral view **I** Abactinal view of the arm, and **J** Actinal view of the arm.

Colour. Extremely variable, usually juveniles and adults having different colours (Hendler et al. 1995). Juvenile individuals have brown, red or violet spots, while adults are uniformly reddish-brown, yellowish-brown, violet, or olive-green (Brito 1960, Hendler et al. 1995, Benavides-Serrato et al. 2011). In the Brazilian material the most common colour observed is brown and yellow.

Distribution. Tropicopolitan (Tommasi 1970, Alvarado et al. 2008). It also occurs throughout the tropical Indo-West Pacific. In Brazil: PB, PE, AL, BA, RJ, and SP, including Abrolhos and Trindade Island (Rathbun 1879, Verrill 1915, Bernasconi 1955, Tommasi 1958, Brito 1960, 1962, 1968, 1971, Lima-Verde 1969, Tommasi and Aron 1988, Fernandes et al. 2002, Magalhães et al. 2005, Gondim et al. 2008, Miranda et al. 2012). From 0 to 298 m in depth (Clark and Downey 1992).

Remarks. Two species of the genus *Linckia* are known for the Brazilian coast, *L. guildingi* and *L. nodosa* Perrier, 1875, the latter recorded only for south and southeastern Brazil. Tommasi and Aron (1988) cite *Ophidiaster guildingi* Gray, 1840 for southeast Bahia, a locality we were not able to confirm. *Linckia guildingi* differs from *L. nodosa* for having small triangular abactinal plates, 18–30 pores per papular area, and two subambulacral spines. Juvenile individuals of *L. guildingi* may be confused with *Ophidiaster guildingi* Gray, 1840, which have the same colour and occupy the same habitat (Hendler et al. 1995). *Ophidiaster guildingi* differs from *L. guildingi* for having less than 15 pores per papular area. Although we observed both juvenile and adult individuals, no morphological variations were noted.

Ecological notes. This species lives in environments with consolidated substrates or sand banks among reefs (Machado et al. 2008). It has cryptic habits, being found mostly under rocks. Possibly *L. guildingi* uses the film of microorganisms adhered to the substrate as food (Hendler et al. 1995; Machado et al. 2008). According to Brito (1971) this species is abundant along the northeastern coast of Brazil. However, its populations are becoming reduced, especially in southeastern Brazil. The species is presently included among the species vulnerable to extinction (Machado et al. 2008). *L. guildingi* is known for its strong propensity to autotomize and its capacity to regenerate. Specimens with four, six or seven arms are common (Tommasi 1958).

Narcissia trigonaria Sladen, 1889

Figure 10f–j

Narcissia trigonaria Sladen, 1889: 414, pl. 65, figs 5–8. Tommasi 1966: 244; 1970: 9, fig. 26. Brito 1960: 5, pl. 1, figs 4–5; 1962: 3; 1968: 5. Tommasi and Aron 1988: 3. Tommasi et al. 1988: 6. Miranda et al. 2012: 144.

Narcissia trigonaria var. *helenae* Mortensen, 1933: 429.

Material examined. Alagoas: Lagoa Azeda, Jequidá da Praia, 1spec., MNRJ (no registration number), 22.VI.2002. Bahia: Salvador, north coast, 1spec., UFBA00570,

2003; Salvador, Porto da Barra, 1spec., UFBA00929, II.2008, 23m; Salvador, Barra Beach, 1spec., UFBA00962, X.2008; Itaparica, Ponta de Areia, 12°52'S; 38°40'W, 1spec., UFBA00469; Camaçari, Guarajuba, 1spec., UFBA00190, VII.2005, 23m; Camaçari, Guarajuba, Busca Vida Beach, 2spec., UFBA00042, 04.VI.1994, 1spec., UFBA01043, VII.2008, 26m, 1spec., UFBA01089, VII.2008, 32m.

Type-locality. Bahia, Brazil (Clark and Downey 1992).

Description. Disk high and pyramidal (Fig. 10f, h). Five long and triangular arms in transversal section (Fig. 10f, h). Abactinal and actinal surfaces granulose (Fig. 10i). Abactinal plates rounded, placed in irregular rows, covered by flattened and polygonal granules. Among these plates are papular areas with up to three papulae. Superomarginal plates short, wide (~2.69 mm), granulose and visible only laterally. Papular areas restricted to abactinal surface. Inferomarginal and superomarginal plates similar. Actinal plates slightly rectangular and granulose, these granules being bigger and taller than the dorsal granules. Actino-lateral plates with two rows of spines, the outer series with 4–5 short and blunt spines. The inner row is formed by 3–4 large, flattened spines, being longer than the outer row. Adambulacral plates with 3–4 series of flattened and prismatic spines, of which the innermost are the largest (Fig. 10j).

Colour. Live specimens are cream-coloured with red spots (Benavides-Serrato et al. 2011).

Distribution. North Carolina, Florida, Panama, Colombia, and Brazil (Tommasi 1970; Clark and Downey 1992; Alvarado et al. 2008; Benavides-Serrato et al. 2011). In Brazil: AL, BA, and RJ (Verrill 1915, Brito 1960, 1962, Tommasi 1970, Tommasi and Aron 1988, Miranda et al. 2012). From 5 to 91 m in depth (Tommasi 1970, Clark and Downey 1992).

Remarks. *Narcissia trigonaria* is a well established species, with a small list of synonyms and little morphological variation. It differs from *N. canariensis* (d'Orbigny, 1839) for having subambulacral spines arranged into three series and paired papulae. Downey (1973) records the sugar-tongs type of pedicellariae among the carinal plates of *N. trigonaria*. However, we did not observe this type of pedicellaria. Walenkamp (1976) gives an excellent discussion on the presence or absence of pedicellariae and on small morphological variations found in his material. He emphasizes the great morphological differences existing between juvenile and adult specimens. In general, very juvenile individuals have shorter and wider arms. These tend to become thinner and longer during ontogenetic development.

Ecological notes. The species lives in consolidated substrates, either rocks or coral (Machado et al. 2008). Presently it is considered vulnerable to extinction along the Brazilian littoral. The main causes of its populational decline are the effects of pollutants and its illegal and indiscriminate collecting for aquarium rearing (Machado et al. 2008).

Order Spinulosida Perrier, 1884**Family Echinasteridae Verrill, 1867*****Echinaster (Othilia) brasiliensis* Müller & Troschel, 1842**

Figure 11a–e

Echinaster brasiliensis Müller & Troschel, 1842: 22. Tommasi 1958: 22–23, pl. 4, fig. 3; 1970: 17, figs 44–45. Brito 1962: 3; 1968: 13–14, pl. 6, fig. 6. Carrera-Rodriguez and Tommasi 1977: 103–104. Tommasi and Aron 1987: 3. Tommasi et al. 1988: 6. Ávila-Pires 1983: 440–442, figs 8–9. Fernandes et al. 2002: 422. Netto 2006: 30–32, pl. 5a. Alves et al. 2010: 758. Miranda et al. 2012: 144.

Echinaster brasiliensis Verrill, 1915: 41–42, pl. 26, fig. 1.

Echinaster antonioensis Bernasconi, 1955: 72–73, pl. 6, figs 1–2. Tommasi 1958: 22, pl. 4, fig. 2. Brito 1968: 15.

Echinaster sentus Bernasconi, 1956: 136–137, pl. 4, fig. 3. Tommasi 1958: 23–24, pl. 4, fig. 4; 1970: 17–18, fig. 46 a 48. Brito 1968: 14, pl. 6, figs 3–4.

Echinaster spinulosus Bernasconi, 1956: 138–139, pl. 4, fig. 4. Tommasi 1958: 21–22, pl. 4, fig. 1. Brito 1968: 14, pl. 6, fig. 1–2.

Echinaster densispinulosus Tommasi, 1970: 18–19, figs 49–51.

Echinaster nudus Tommasi, 1970: 18–19, figs 52–54. Gondim et al. 2008: 154.

Echinaster (Othilia) brasiliensis Clark & Downey, 1992: 21–22, pl. 4a. Hopkins et al. 2003: 98–100. Machado et al. 2008: 182–183. Lima and Fernandes 2009: 59. Xavier 2010: 75.

Material examined. Rio Grande do Norte: Macau, Diogo Lopes, 1spec., UFPB/ECH.869, 09.XI.2007, 1spec., UFPB/ECH.872, 09.XI.2008, 1spec., UFPB/ECH.1426, 09.XI.2007. Paraíba: 7°01'02"S; 34°47'55"W, 1spec., UFPB/ECH.571, 03.VI.2003; 7°03'50"S; 34°47'19"W, 1spec., UFPB/ECH.569, 21.III.2006; Cabedelo, Farol de Cabedelo reef, 1spec., UFPB/ECH.729, 26.X.1980; Cabedelo, Areia Vermelha reef, 1spec., UFPB/ECH.1465, 22.II.2008; João Pessoa, Cabo Branco Beach, 2spec., UFPB/ECH.138, 04.XI.2006; João Pessoa, Seixas reef, 1spec., UFPB/ECH.1183, 22.XII.2007. Bahia: Santo Amaro, Cabuçu Beach, 3spec., UFPB/ECH.718, 19.IX.1987.

Type-locality. Ubatuta, São Paulo, Brazil (Walenkamp 1976).

Description. Disk small (Fig. 11a). Body concave on abactinal surface, plane on actinal surface. Five long-narrow to short-thick arms (usually decreasing rapidly in thickness towards tips) (Fig. 11a, b). Abactinal plates flattened or slightly mamiform (Fig. 11e), forming a reticulum and bearing a short, conical spine (Fig. 11c). Abactinal plates separated by small, elongated, secondary plates. Anus normally placed within the central pentagon of the disk and surrounded by 4–6 spines. Madreporite circular, with numerous small granules and irregular sulci. Superomarginal plates more granulose than inferomarginal plates. Papular areas more numerous on dorsal and lateral regions of arms (Fig. 11c). Adambulacral plates with three spines,

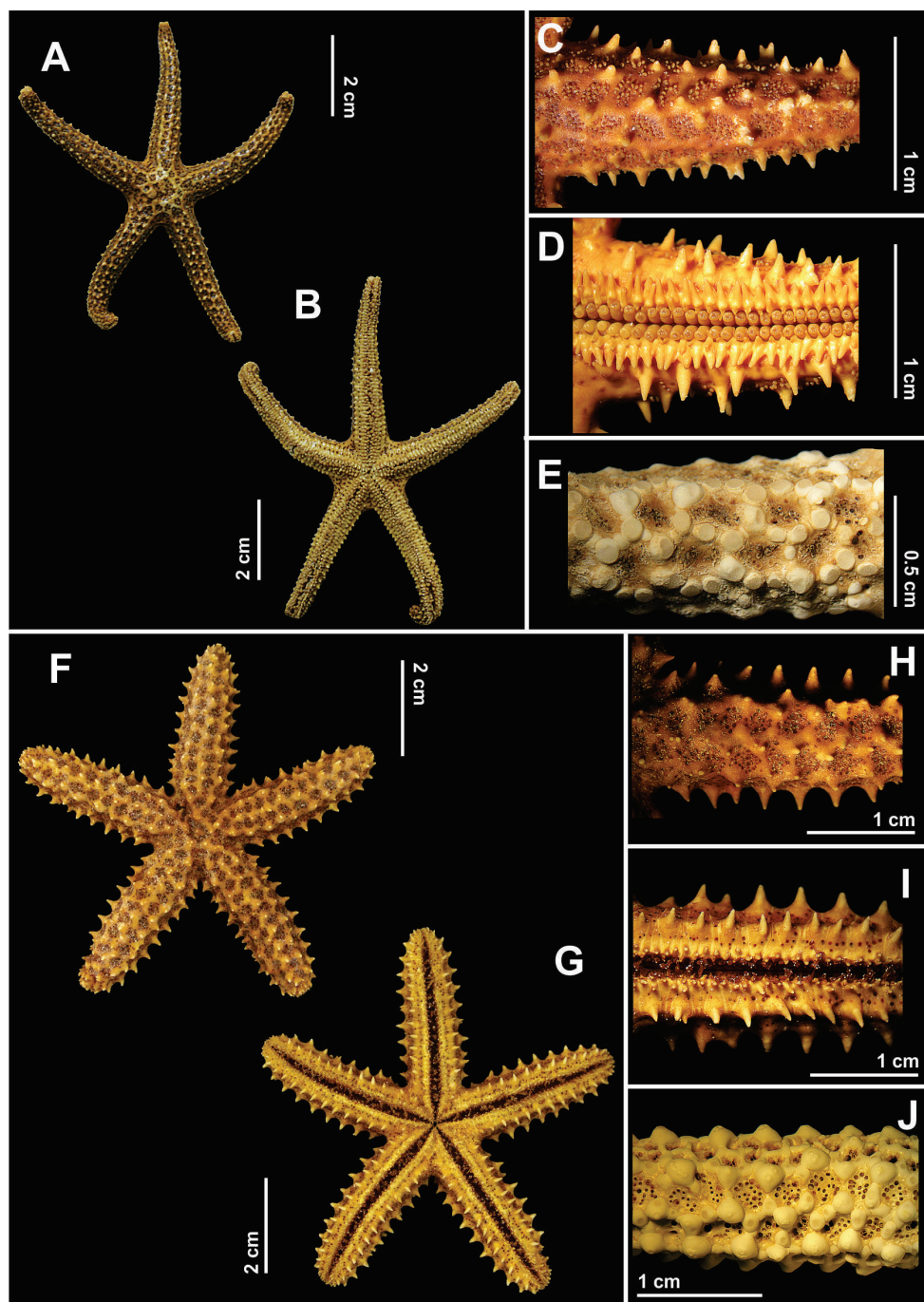


Figure 11. Some species of the order Spinulosida recorded in northeastern Brazil. *Echinaster (Othilia) brasiliensis* (A–E) **A** Abactinal view **B** Actinal view **C** Abactinal view of the arm **D** Actinal view of the arm **E** Arranjo do endoesqueleto do braço; *Echinaster (Othilia) echinophorus* (F–J) **F** Abactinal view **G** Actinal view **H** Abactinal view of the arm **I** Actinal view of the arm; and **J** Arranjo do endoesqueleto do braço.

the inner one being rudimentary (Fig. 11d). The two outer spines are subequal and larger than the remaining spine.

Colour. Quite variable, being light brown, reddish-brown, dark red or even yellowish red (Gray et al. 1968; Benavides-Serrato et al. 2011).

Distribution. Florida, Cuba, Honduras, Panama, Colombia, Brazil, and Argentina (Tommasi 1958, Alvarado et al. 2008, Benavides-Serrato et al. 2011). In Brazil: PB, PE, AL, BA, ES, SP, RJ, SC, and RS (Verrill 1915, Tommasi 1958, Carrera-Rodriguez and Tommasi 1977, Fernandes et al. 2002, Magalhães et al. 2005, Gondim et al. 2008, Xavier 2010, Miranda et al. 2012). This paper provides the first record for the State of Rio Grande do Norte. From 1 to 360 m in depth (Benavides-Serrato et al. 2011).

Remarks. Many characters of *Echinaster (O.) brasiliensis* and other species of the genus present great plasticity, with the consequence that the taxonomy of the genus cannot be considered well resolved. *E. (O.) brasiliensis* differs from *E. (O.) echinophorus* for presenting a larger number of rows of dorsal longitudinal spines (9–15) and actinal plates not mammiform. *E. (O.) sentus* differs for having more numerous and shorter dorsal spines and for having mammiform abactinal plates. Walenkamp (1976) pointed out some variations observed in specimens from Suriname, such as: number of ambulacral spines (from 2 to 5), number of spines per dorsal longitudinal row (from 1 to 15), and size of the dorsal papular areas. In our study, as well as the large plasticity in the number of dorsal longitudinal spines (from 7 to 13), a character used as diagnostic for the genus, the number of spines surrounding the anus and the shape of the arms also proved to be quite variable. However, these morphological variations do not seem to be related to ontogenetic stages. Despite both adults and juveniles being present in our material, these variations occurred among specimens of a same size class. According to Machado et al. (2008), the most common shape of *E. (O.) brasiliensis* presents narrow and elongate arms, while a smaller proportion of individuals have short and thick arms and less numerous spines. Tommasi (1970) synonymized *E. (O.) antonioensis* De Loriol, 1904 with *E. (O.) brasiliensis*, though without providing further details. According to him (Tommasi *op. cit.*) the characters used by De Loriol to distinguish the two species are all dependent on fixation mode or represent highly variable characters. An excellent discussion on the synonyms of the several species of *E. (O.) brasiliensis* is found in Clark and Downey (1992). Avila-Pires (1983) proposed the presence of only two species of *Echinaster* for the Brazilian littoral, *E. (O.) echinophorus* being restricted to the northeastern coast and *E. (O.) brasiliensis* to the south and southeastern coast. We disagree with this opinion, suggesting that *E. (O.) brasiliensis* also occurs in northeastern Brazil. More taxonomic studies are clearly needed in order to better establish the interspecific limits between these two species.

Ecological notes. This species lives in sand, substrates of sand with mud, and consolidated substrates, often associated with the bivalves *Mytillus* sp. and *Lithophaga* sp. (Penchaszadeh 1973), having also been observed in banks of *Thalassia* sp. (Benavides-Serrato et al. 2011). *Echinaster (O.) brasiliensis* is frequently found in intertidal regions or shallow waters, and may be strongly influenced by water salinity (Machado et al. 2008). In this study, the species was found mainly in reef environments and

hypersaline mangrove areas, always together with *E. (O.) echinophorus*. According to Machado et al. (2008), this species is common along the coast of Rio de Janeiro, being intensively collected by aquarists without further control on their extraction and commercialization. Alves and Dias (2010) recorded its use for medical purposes (treatment of asthma). *E. (O.) brasiliensis* is listed among the species vulnerable to extinction (Machado et al. 2008).

***Echinaster (Othilia) echinophorus* (Lamarck, 1816)**

Figures 11e–j, 12e–f

Asterias spinosa Retzius, 1805: 18.

Asterias echinophora Lamarck, 1816: 560.

Stellonia spinosa Nardo, 1834: 716.

Othilia spinosa Gray, 1840: 281.

Echinaster spinosus Müller & Troschel, 1842: 22.

Echinaster (Othilia) crassispina Verrill, 1868: 368.

Echinaster crassispinus Lütken, 1872: 285.

Echinaster echinophorus Perrier, 1875: 100–102. Brito 1962: 3. Lima-Verde 1969: 11.

Avila-Pires 1983: 436–440, figs 6–7. Tommasi 1970: 16–17, figs 41–43. Tommasi and Aron 1988: 3. Fernandes et al. 2002: 422. Gondim et al. 2008: 155, fig. 3a. Alves et al. 2010: 757. Miranda et al. 2012: 144.

Othilia echinophora Fisher, 1919: 432.

Echinaster (Othilia) echinophorus Clark & Downey, 1992: 367–371. Magalhães et al. 2005: 63. Machado et al. 2008: 183–184. Lima and Fernandes 2009: 59. Gondim et al. 2011: 6, fig. 3e.

Material examined. Rio Grande do Norte: Macau, Diogo Lopes, 4spec., UFPB/ECH.871, 09.XI.2007; Tubarão River, 1spec., UFPB/ECH.1905, 14.XI.2009; Tubarão River Mangrove, 1spec., UFPB/ECH.1904, 31.I.2011; 1spec., UFPB/ECH.1913, 04.IX.2010; Mangrove on highway to Galinhos, 1spec., UFPB/ECH.1914, 22.VI.1982. Paraíba: 7°03'50"S; 34°47'19"W, 2spec., UFPB/ECH.568, 21.III.2006; Lucena, Fagundes Beach, 2spec., UFPB/ECH.717, 22.IX.1995, 1spec., UFPB/ECH.728, 22.IX.1985; Cabedelo, Areia Vermelha reef, 2spec., UFPB/ECH.1464, 06.IV.2008; Cabedelo, Poço Beach, reefs facing Ponta de Campina, 1spec., UFPB/ECH.1903, 28.II.2010; João Pessoa, 7°4'30" S; 34°46'56", 1spec., UFPB/ECH.725, 26.IV.2005; João Pessoa, Cabo Branco Beach, 3spec., UFPB/ECH.704, 2002, 4spec., UFPB/ECH.705, 9spec., UFPB/ECH.706, 04.IV.1981, 4spec., UFPB/ECH.707, 03.VII.1985, 1spec., UFPB/ECH.708, 17.II.1980, 1spec., UFPB/ECH.710, 01.IV.2006, 1spec., UFPB/ECH.711, V.1980, 2spec., UFPB/ECH.713, 06.XI.1983, 10spec., UFPB/ECH.714, 29.IV.2002, 3spec., UFPB/ECH.715, 13.XII.1985, 1spec., UFPB/ECH.719, 22.IX.1980, 3spec., UFPB/ECH.722, 09.II.2001, 1spec., UFPB/ECH.727, 09.IX.2006, 3spec., UFPB/ECH.870,

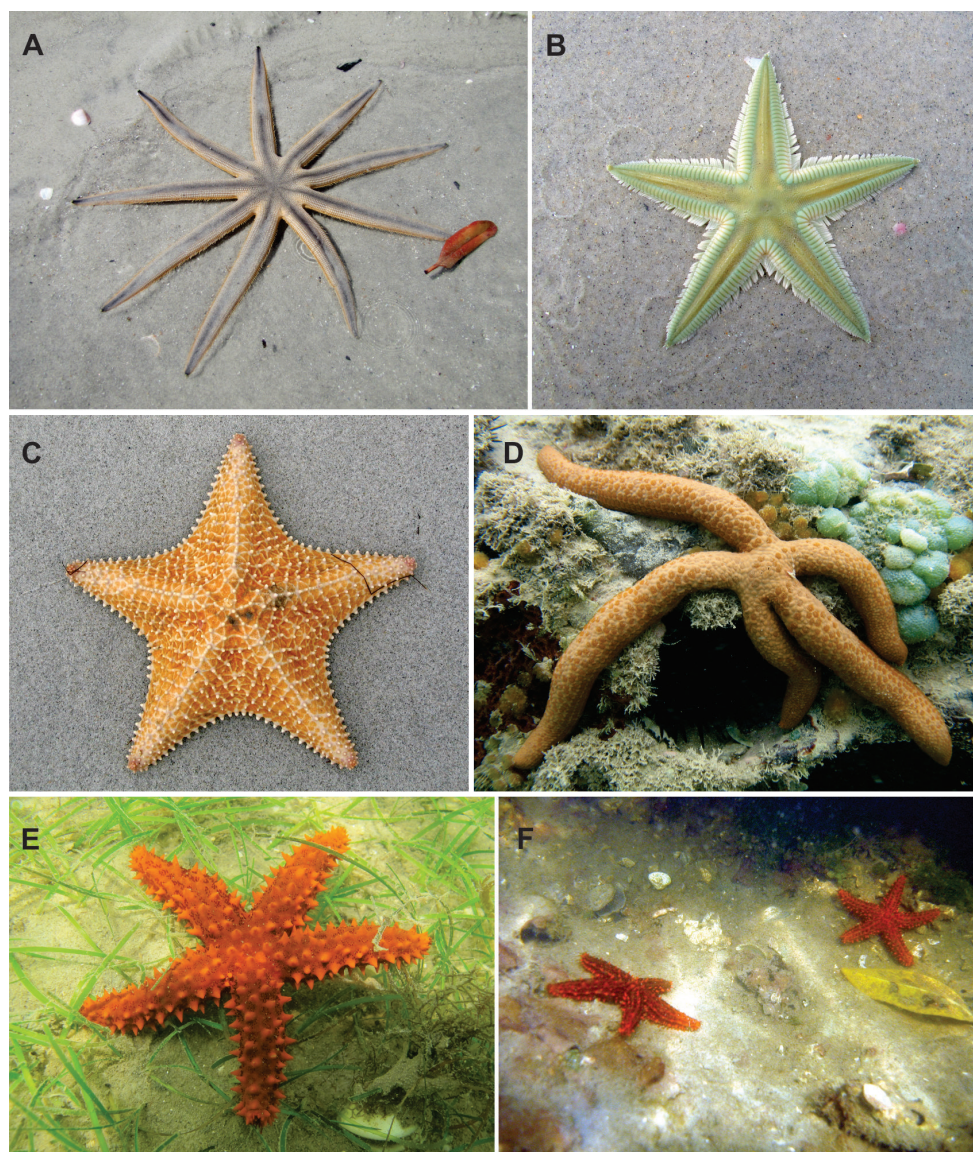


Figure 12. Some common starfishes in their natural habitat. **A** *Luidia senegalensis* in a sand beach **B** *Astropecten marginatus* in a hypersaline mangrove **C** *Oreaster reticulatus* in a sand beach **D** *Linckia guildingi* on coral reefs **E** *Echinaster* (*O.*) *echinophorus* in seagrass beds and **F** *E. (O.) echinophorus* over the muddy bottom of a hypersaline mangrove. Photos: Thelma LP Dias.

25.XI.2007, 1spec., UFPB/ECH.1240, 22.IX.1980, 2spec., UFPB/ECH.1466, 13.XI.2008, 1spec., UFPB/ECH.1911, 21.III.2000; João Pessoa, Ponta Seixas, 6spec., UFPB/ECH.139, 03.XI.1982, 3spec., UFPB/ECH.703, 23.X.1984, 2spec., UFPB/ECH.712, 25.V.1998; Seixas reef, 1spec., UFPB/ECH.1172, 23.III.2008, 6spec., UFPB/ECH.1234, 03.XI.1982. 4spec., UFPB/ECH.1184, 22.XII.2007, 2spec.,

UFPB/ECH.1463, 12.I.2009. Pernambuco: Goiana, Catuama Beach, 1spec., UFPB/ECH.1912, 31.X.1982. UFPB/ECH.873; Tamandaré, Carneiros Beach, 4spec., 15.X.1981. Alagoas: Marechal Deodoro, Francês Beach, 1spec., UFPB/ECH.721, 29.I.1983. Bahia: Itaparica, Pedrão de Itaparica, 8spec., UFPB/ECH.716, 18.IX.1982; Itaparica, Ponta de Aratuba, 7spec., UFPB/ECH.723, 19.X.1982; Itaparica, Barra Grande, 2spec., UFPB/ECH.726, 19.IX.1982; Prado, coral reef between Camaruxatiba and Ponta de Imbaçuaba, 3spec., UFPB/ECH.709, 14.X.1982, 2 spec., UFPB/ECH.724, 28.XI.1982; Santa Cruz da Cabralia, Ponta da Coroa Vermelha, 5spec., UFPB/ECH.720, 15.X.1982.

Type-locality. ‘Amérique du Nord’ (lectotype) (Clark and Downey 1992).

Description. Disk small (Fig. 11f). Body convex dorsally and flattened ventrally. Five (rarely three to six) short and thick arms, with a robust skeleton (Fig. 11f, g). Abactinal plates mammiform (Fig. 11j), with one large spine. Seven to 11 series of dorsal longitudinal spines. Anus normally positioned within central pentagone of disk and surrounded by 4–6 spines. Madreporite circular with numerous small granules and irregular grooves. Papular areas more numerous on abactinal and lateral regions of arms (Fig. 11h). Papular areas on actinal surface small and widely dispersed. Adambulacral plates with 3 to 4 spines arranged transversally (Fig. 11i).

Colour. Red, orange-red, becoming brownish-red when conserved in alcohol and dark brown when dry (Verrill 1915, Hendler et al. 1995).

Distribution. Florida, the Bahamas, Gulf of Mexico, Puerto Rico, Jamaica, Nicaragua, Colombia, Venezuela, and Brazil (Alvarado 2011, Benavides-Serrato et al. 2011). In Brazil: CE, RN, PB, PE, AL, BA, ES, and RJ, including Abrolhos (Verrill 1915, Krau 1950, Brito 1962, Lima-Verde 1969, Tommasi 1970, Avila-Pirez 1983, Fernandes et al. 2002, Magalhães et al. 2005, Miranda et al. 2012). From 0 to 55 m in depth (Hendler et al. 1995).

Remarks. *Echinaster (O.) echinophorus* differs from *E. (O.) sentus* for having few large and conspicuous spines on arms and a uniform colour (Hendler et al. 1995). It differs from *E. (O.) brasiliensis* for having thicker arms and mammiform abactinal plates. According to Atwood (1973), *E. (O.) echinophorus* appears to contain several morphologically distinct forms or closely related species. For Walenkamp (1979) the number of series of dorsal longitudinal spines, which Perrier considered to be the main character for separating species in the genus, is quite variable. The examined specimens have a broad morphological variation, among which: number of rows of dorsal longitudinal spines (from 7 to 9), number of spines surrounding the anus (from 4 to 6) and number of granules on the madreporite (from 8 to 15). Notwithstanding, these morphological variations do not seem to be related to ontogenetic development, because even though specimens examined included both juvenile and adult individuals, the differences also affected specimens of the same size. An excellent discussion of the synonymies proposed for the different species of *E. (O.) echinophorus* and of the taxonomic history of the species is found in Clark and Downey (1992) and Walenkamp (1979).

Ecological notes. Lives usually in environments containing consolidated substrates (Hendler et al. 1995), and may be found in estuarine regions (Nobre and

Campos-Creasey 2000). It feeds preferably on incrustating organisms belonging to the epifauna and on organic detritus deposited in the substrate (Jangoux and Lawrence 1982). Kempf (1966) found that *E. (O.) echinophorus* may occur in salinities up to 47. We found it in salinities of 52 (Tubarão River/Rio Grande do Norte), forming dense populations. Alves and Dias (2010) commented on the use of this species for medicinal purposes and Machado et al. (2008) remarked that one of the main threats relates to its collecting for aquarists. Presently it is included among the Brazilian species vulnerable to extinction (Machado et al. 2008).

Order Forcipulatida Perrier, 1884

Family Asteroiidae Gray, 1840

Coscinasterias tenuispina (Lamarck, 1816)

Figure 9i–m

Asterias tenuispina Lamarck, 1816: 561–562.

Asteracanthion tenuispinus Müller & Troschel, 1842: 16.

Asterias atlantica Verrill, 1868: 368. Rathbun 1879: 145.

Asterias (Stolasterias) tenuispina Sladen, 1889: 565, 583.

Polyasterias tenuispina Perrier, 1894: 108.

Lytaster inaequalis Perrier, 1894: 98–99.

Coscinasterias tenuispina Verrill, 1914: 45. Brito 1960: 4; 1962: 2. Netto 2006: 34, fig. 16c, pl. 5b. Ventura et al. 2007: 228.

Coscinasterias tenuispina var. *atlantica* Verrill, 1915: 20–21. Tommasi 1966: 24–244.

Stolasterias tenuispina Verrill, 1907: 324.

Coscinasterias (Stolasterias) tenuispina Fisher, 1926: 197.

Material examined. Rio de Janeiro: Cabo Frio, Formoso Beach, 1 spec., MZUSP (without registration number), VII.1956; Cabo Frio, Arraial do Cabo, Brava Beach, 1 spec., MZUSP (without registration number), 29.I.2001.

Type locality. ‘l’ ocean eropéen’ (Clark and Downey 1992).

Description. Disk small, with 1–3 madreporites (in some cases up to 5 were observed). Six to nine (rarely 5 and unusually 7) thin, elongate (Fig. 9i, j), cylindrical arms, usually of different sizes, the larger ones grouped to one side and the smaller ones to the opposing side. Abactinal plates with one long, conical and pointed spine (~2.17 mm), with base densely surrounded by bivalve pedicellariae with overlapping valves (Fig. 9l). Carinal plates arranged in a regular series. Dorso-lateral plates forming a reticulum. Papular regions occurring on the abactinal and actinal surfaces. Among the abactinal plates, mainly in the intermediate areas, large bivalve pedicellariae are found. Pedicellariae of dorsal spines sessile and with overlapping bivalves, with denticulate margins. Oral pedicellariae bivalve (Fig. 9m), consisting of a basal piece into which two valves with smooth margins fit in.

Colour. Specimens from Brazil vary from brown to orange colour (Ventura et al. 2007). According to Clark and Downey (1992), specimens from the Mediterranean are usually yellow or whitish-yellow with black or brown spots on abactinal surface and crowns of rusty-red pedicellariae. Individuals from the Bermudas, on the other hand, with dorsal surface purple and the oral surface yellow, blue or violet (Verrill 1915).

Distribution. North Carolina, Gulf of Mexico, Antilles, Bermudas, Cuba, Brazil, Portugal, Spain, France and Montenegro (Tommasi 1970, Downey 1973, Clark and Downey 1992, Alves et al. 2002, Waters and Roy 2003, Kascelan and Mandic 2007). In Brazil: BA, ES, and SP, including Abrolhos (Rathbun 1879, Verrill 1915, Brito 1960, Tommasi 1970, Ventura et al. 2007). Intertidal to 165 m in depth (Clark and Downey 1992).

Remarks. Two species of the genus *Coscinasterias* Verrill, 1870 are known for the Atlantic, *C. tenuispina* and *C. calamaria* (Gray, 1840). The first is widely distributed through the Atlantic and Mediterranean, while the second is restricted to South Africa, Angola, and Madagascar (Mah 2013). *C. tenuispina* differs from *C. calamaria* for having intercrossing pedicellariae with a well developed terminal tooth (except in some specimens from Brazil). Clark and Downey (1992) suggested a subspecific distinction for these species on the basis of morphological similarities observed in Brazilian and South African specimens. However, according to Waters and Roy (2003) these observations were made on the basis of juvenile specimens and it is thus necessary to undertake new morphological analyses to clarify the close relationships between *C. calamaria* and *C. tenuispina* (Waters and Roy 2003). In the phylogeographic analysis of Waters and Roy (op. cit.) for species of *Coscinasterias*, morphological variations were observed between populations from Brazil on the one side and from the Bermudas and the Mediterranean on the other. No morphological variations are observed in the specimens examined by us.

Ecological notes. Lives in consolidated substrates, including areas with strong hydrodynamism (Machado et al. 2008). *Coscinasterias tenuispina* has extra-oral digestion and feeds on epifaunal organisms, mainly mussels (Ventura et al. 2007). It is a fissiparous species, which presents an annual gonadal cycle and a long period of spawning (Alves et al. 2002). According to these authors, the preponderance of males in the population of Itaipu Beach (Niterói/Rio de Janeiro) suggests that asexual reproduction by fission is predominant and, consequently, that the number of clones must be significant. According to Brito (1962), this species is very common in Cabo Frio (Rio de Janeiro). However, since the first record by Rathbun (1879) of *C. tenuispina* for Abrolhos (Bahia), the species has not been cited again off the northeast region of Brazil. As pointed out by Machado et al. (2008), although this species has a wide geographical distribution, its range is discontinuous, probably due to its asexual reproduction, that limits dispersal ability. Presently the species is listed among those vulnerable to extinction, having among the main causes of population decline the constant destruction of its habitat, the erosion of the substrate, the effects of pollutants, the precarious sanitation and the excess of tourists and divers within their range of occurrence (Machado et al. 2008).

Discussion

The fauna of Asteroidea recorded for northeastern Brazil is composed mainly by species with broad geographical and bathymetric distributions, and considered common species for the Brazilian littoral (Tommasi 1970). One exception is *Mithrodia clavigera*, which represents a new record for the northeast and is typically a species of deeper waters. Another two species represent new records for northeast Brazil: *Astropecten alligator* and *Luidia ludwigi scotti*.

Among the four recorded orders, Paxillosida was the most diverse ($n = 10$ spp), followed by Valvatida ($n = 5$ spp), Velatida ($n = 3$ spp), Spinulosida ($n = 2$ spp) and Forcipulatida ($n = 1$ spp). These results were expected, because Paxillosida represents the most diverse order and contains the most speciose genus (*Astropecten* with 150 spp) and abundant species in shallow waters (Zulliger et al. 2010). Although common in marine communities, the taxonomy of the species composing this order and the phylogenetic relationships of the Paxillosida are still uncertain and contradictory (Matsubara et al. 2005). During many years this order was considered to be the most primitive in the class, due mainly to the absence of an anus and of ventosae on the ambulacral feet (Jangoux 1982). However, a reexamination of characters evidenced that these characters represent adaptations to life in sandy environments that produced character losses instead of being primitive absences (Matsubara et al. 2005).

The genus *Astropecten* represents one of the most complex taxa within the class Asteroidea, in which species exhibit great morphological plasticity, making identification of species difficult. According to Zulliger et al. (2010), the high phenotypic variability of this genus resulted in the naming of several subspecies. Six of these were recognized in Brazil (Tommasi 1970). Presently they are all synonymized (Clark and Downey 1992; Mah 2013) and the records of *Astropecten armatus* for the Brazilian coast represent synonyms of *A. brasiliensis* (Tommasi 1999, unpublished data). Among the several taxonomic characters used for the identification of species, the appearance of the paxillae and of the superomarginal plates, together with the number and shape of the spines of the marginal fringe are the characters that contribute most for the identification of species. On the other hand, the number and shape of the adambulacral spines, characters that were much used by authors such as Bernasconi (1955, 1957), Tommasi (1970) and Clark and Downey (1992), proved to be very similar among specimens and were thus not considered to be good characters for the taxonomy of the genus.

Another taxonomically complex genus is *Echinaster* that, similarly to *Astropecten*, presents large morphological variability, making species identification difficult. According to Clark and Downey (1992), the species of this genus occurring in Brazil are polymorphic, with possible hybridization among them. Presently three occurrences of *Echinaster* (*Othilia*) are considered valid along the Brazilian coast: *E. (O.) brasiliensis*, *E. (O.) echinophorus*, and *E. (O.) guyanensis*. According to Avila-Pires (1983), the first occurs only in the south and southeastern regions, below Espírito Santo, and the second is restricted to the northeastern region. That author does not confirm the presence of *Echinaster (O.) guyanensis*, but Clark and Downey (1992) indicate its distribution as being from Cen-

tral America to Belém (Pará). Magalhães et al. (2005) recorded *E. (O.) guyanensis* for the littoral of Bahia, but this occurrence could not be confirmed in the present study. On the basis of the material we examined we cannot agree with Avila-Pires (1983) that *E. (O.) brasiliensis* does not occur in the northeastern region. We confirm its presence in northeastern Brazil, although it is rarer there than its congener *E. (O.) echinophorus*. Among the several characters used in the taxonomy of the genus, the aspect of the endoskeleton plates represent one of the most important criteria for species recognition. The number of spine rows on the arms was used by Avila-Pires (1983) and Bernasconi (1957) to separate species, but it turned out to be quite variable in this study.

In terms of diversity, the fauna of asteroids in northeastern Brazil represent only 27% of the species known for Brazil, the coast of Bahia ($n = 14$ spp) and Paraíba ($n = 12$ spp) being the most diverse, followed by Pernambuco ($n = 9$ spp), Ceará and Rio Grande do Norte (both with 6 spp), Alagoas ($n = 4$ spp), and Piauí ($n = 2$ spp). There are still no records of asteroids for the coasts of Maranhão and Sergipe. These numbers indicate the scarce knowledge available on the Asteroidea from northeast Brazil, which represents one of the least known areas regarding the benthic macrofauna (Ventura et al. 2007). The species referred for northeast Brazil ($n = 21$ spp) are mostly shallow water species (up to 30 meters in depth), with only 4 species representing deep-water forms. It remains crucial to conduct inventories in little explored areas such as northeast Brazil, particularly in deep waters.

Presently 374 species of sea-stars are known for the Atlantic Ocean (Clark and Downey 1992), the Gulf of Mexico being the most speciose area, with 126 recorded species (Pawson et al. 2009), followed by the Caribbean, with 116 spp (Alvarado et al. 2011). The fauna from Brazil represents only 20.5% of the known species from the Western Atlantic, while those from northeast Brazil represent 4.82%. Considering the similarity of the Brazilian fauna with the Caribbean region, and taking into account the extent of the Brazilian coastline, the necessity to make an inventory and to describe the Brazilian fauna becomes urgent. According to Marques and Lamas (2006), the degree of knowledge of the marine fauna from Brazil is far from ideal and the most notable gap in our knowledge refers to the invertebrates mainly from northeast Brazil.

Another three species recorded previously for northeast Brazil were not confirmed in the present study: *Allostichaster hartti* (as *Leptasterias hartii* Rathbun, 1879) was recorded as a rare species for the littoral of the State of Bahia (Brito 1962); *Asterina stellifera* (Möbius, 1859) (as *Enoplopatiria marginata* (Hupe, 1857)) was cited by Bernasconi (1955) for the Abrolhos Archipelago and *Echinaster (O.) guyanensis* was recorded by Magalhães et al. (2005) for the coast of Bahia. Ventura et al. (2007) cited *A. acutiradiatus*, *N. arenatus* and *P. dentatus* for the continental shelf of Bahia. Unfortunately, we have been unable to retrieve these species in the present study.

Due to the negligible previous knowledge on the Asteroidea from the littoral of northeastern Brazil, the present study represents an important re-evaluation of the diversity of this group for this area. It should further be noted that the study of material deposited in scientific collections turned out to be of fundamental importance, permitting a historical panorama of the Asteroidea from northeast Brazil. Deep-water sampling in the studied

region, restricted to sporadic expeditions, as accounted for in Clark and Downey (1992), has still not provided many published records on asteroids. The diversity of the deep-water and abyssal marine fauna of the South West Atlantic perhaps remains the least known in the world, and clearly represents the next marine frontier to be systematically sampled and studied, both for asteroids and for other marine groups.

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An unusual new species of paguroid (Crustacea, Anomura, Paguridae) from deep waters of the Gulf of Mexico

Rafael Lemaitre¹, Ana Rosa Vázquez-Bader², Adolfo Gracia²

1 Department of Invertebrate Zoology, National Museum of Natural History, Smithsonian Institution, 4210 Silver Hill Road, Suitland, MD 20746, USA **2** Laboratorio de Ecología Pesquera de Crustáceos, Instituto de Ciencias del Mar y Limnología, UNAM, Av. Universidad # 3000, Universidad Nacional Autónoma de México, CU, Distrito Federal, 04510, México

Corresponding author: Rafael Lemaitre (lemaitrr@si.edu)

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Abstract

A new hermit crab species of the family Paguridae, *Tomopaguropsis abkinpechensis* **sp. n.**, is described from deep waters (780–827 m) of the Gulf of Mexico. This is the second species of *Tomopaguropsis* known from the western Atlantic, and the fifth worldwide. The new species is morphologically most similar to a species from Indonesia, *T. crinita* McLaughlin, 1997, the two having ocular peduncles that diminish in width distally, reduced corneas, dense cheliped setation, and males lacking paired pleopods 1. The calcified plates on the branchiostegite and anterodorsally on the posterior carapace, and the calcified first pleonal somite that is not fused to the last thoracic somite, are unusual paguroid characters. A discussion of the affinities and characters that define this new species is included, along with a key to all five species of *Tomopaguropsis*.

Keywords

Tomopaguropsis, new species, Paguridae, hermit crab, deep water, Gulf of Mexico

Introduction

Few deep ocean basins have been sampled or studied more intensely than the Gulf of Mexico. From the late 1800s to the 1940s, only a handful of stations had been sampled in the Gulf, primarily during cruises of the US Coast and Geodetic Survey's steamer

Blake, US Fish Commission Steamer *Albatross*, HP Bingham's yacht *Pawnee I*, and Woods Hole Oceanographic Institution's R/V *Atlantis* (Bayer 1969, Pequegnat and Chace 1970). Since the 1950s, however, the Gulf has been crisscrossed by numerous exploratory or oceanographic expeditions, particularly on board the R/V *Oregon*, R/V *Oregon II*, M/V *Silver Bay*, M/V *Combat*, R/V *Pelican*, R/V *Pillsbury*, R/V *Alaminos*, and B/O *Justo Sierra* (Bullis and Thompson 1965, Pequegnat and Chace 1970, Vázquez-Bader and Gracia 2013, Vázquez-Bader et al. 2014), which altogether have accumulated in museums and research institutions a vast collection of invertebrates discussed in numerous taxonomic reports (see summary in Felder and Camp 2009). Yet, new species are still being discovered in deep waters of the Gulf, as documented in this paper with the description of a new hermit crab of the family Paguridae.

During the 2011 and 2013 cruises of the B/O *Justo Sierra* of the Universidad Nacional Autónoma de México (UNAM), as part of studies of the deep water (300–1200 m) benthic communities and fishery resources from the Mexican coast, two male specimens of an unusual species of hermit crab were collected in deep water near the Campeche Bank. A study of these relatively large specimens (about 65 mm in stretched body length) showed they represent an undescribed species assignable to *Tomopaguropsis* Alcock, 1905, a genus previously known to be represented in the western Atlantic by a single species only, *T. problematica* (A. Milne-Edwards & Bouvier, 1893). McLaughlin (1997) discussed and expanded *Tomopaguropsis* with the description of two new species from Indonesian waters, *T. crinita* McLaughlin, 1997, and *T. miyakei* McLaughlin, 1997, and selected *T. lanata* Alcock, 1905, from the Indian Ocean, as the type species of the genus, although McLaughlin (1997: 546, 552; 2003: 128) consistently misspelled the type species name as "*T. lantana*". In addition to their deep water habitat, usually ranging from continental shelf to upper slope depths (about 100 to 750 m), the previously known species of this genus are characterized primarily by having 13 pairs of quadriserial gills; crista dentata with accessory tooth; chelipeds subequal (right slightly more robust); fourth pereopod with propodal rasp consisting of several rows of corneous scales, dactyl with or without preungual process; and males and females with unpaired left pleopods 2–5, males often but not always, with paired small pleopods 1 modified as gonopods. The new species of *Tomopaguropsis* is fully described, and its affinities with other congeners and some unusual characters of phylogenetic significance, are discussed.

Materials and methods

The holotype of the new species described herein is deposited in the collections of the Laboratorio de Ecología Pesquera de Crustáceos, Instituto de Ciencias del Mar y Limnología, UNAM (EPC), and a paratype in the National Museum of Natural History, Smithsonian Institution, Washington DC (USNM). The specimens were collected during deep-water cruises of the B/O *Justo Sierra*, using a commercial shrimp trawl with an 18 m opening, equipped with a net having 4.5 cm mesh size along the body,

and 1.5 cm mesh size on the cod end. Each trawl lasted for 30 min at a ship speed of 2.5 to 3.0 knots. Samples were sorted and preserved in 70% ethanol and transported to the Laboratorio de Ecología Pesquera de Crustáceos of Instituto de Ciencias del Mar y Limnología, UNAM, for study.

General terminology follows that used by McLaughlin and Lemaitre (2001), with specialized terminology for the lines and calcified portions of branchiostegite and posterior carapace after Tudge et al. (2012). Pereopods and pleopods are indicated with a number, except for chelipeds which correspond to pereopods 1. Measurements indicated for the specimens are of shield length, measured in millimeters (mm) from the midpoint of rostral lobe to midpoint of posterior margin of shield. Abbreviations: B/O, buque oceanográfico; COBERPES, Comunidades Bentónicas y Recursos Pesqueros Potenciales del Mar Profundo del Golfo de México; R/V, research vessel; sta, station.

Taxonomy

Family Paguridae Latreille, 1802

Tomopaguropsis abkinpechensis sp. n.

<http://zoobank.org/411C7597-63C1-4085-9748-FEC4CDFEFFBC>

Figs 1–4

Type material. Holotype: COBERPES 3, sta α10, 19°40.066N, 92°45.490W, 780 m, 19 November 2011: 1 male 8.9 mm (EPC 201310). Paratype: COBERPES 5, sta A11, 19°32.108N, 93°08.373W, 827 m, 24 May 2013: 1 male 8.1 mm (USNM 12376795).

Description. Thirteen pairs of quadriserial gills. Arthrobranchs on third maxilliped and somite X (thoracomere 4, or cheliped) well developed. Pleurobranchs well developed on each of somites XI–XIII (thoracomeres 5–7, above second to fourth pereopods).

Shield (Figs 1A, B, 2A) slightly longer than broad, well calcified, with short transverse rows of setae arranged longitudinally on each side from near lateral projections to near posterior margin of shield. Rostrum broadly triangular, ending roundly or in sharp spine. Anterior margins between rostrum and lateral projections concave. Lateral projections ending in sharp spine. Anterolateral margins sloping. Posterior carapace with lateral lobes (“accessory portions” of McLaughlin and Lemaitre 2001) fused to shield; with well calcified and delimited posteromedian and posterolateral plates (Figs 2A). Branchiostegite (Figs 1C, 4A) with 2 narrow calcified plates: 1 anterodorsal, and 1 posterior curving down adjacent to sulcus verticalis and bifurcated ventrally.

Ocular peduncles (Figs 1A, B, 2A) less than half length of shield, inflated basally and diminishing in width distally, with dorsomesial, longitudinal row of long setae; corneas reduced not dilated. Ocular acicles subtriangular, terminating in strong spines with mesial margins nearly contiguous.

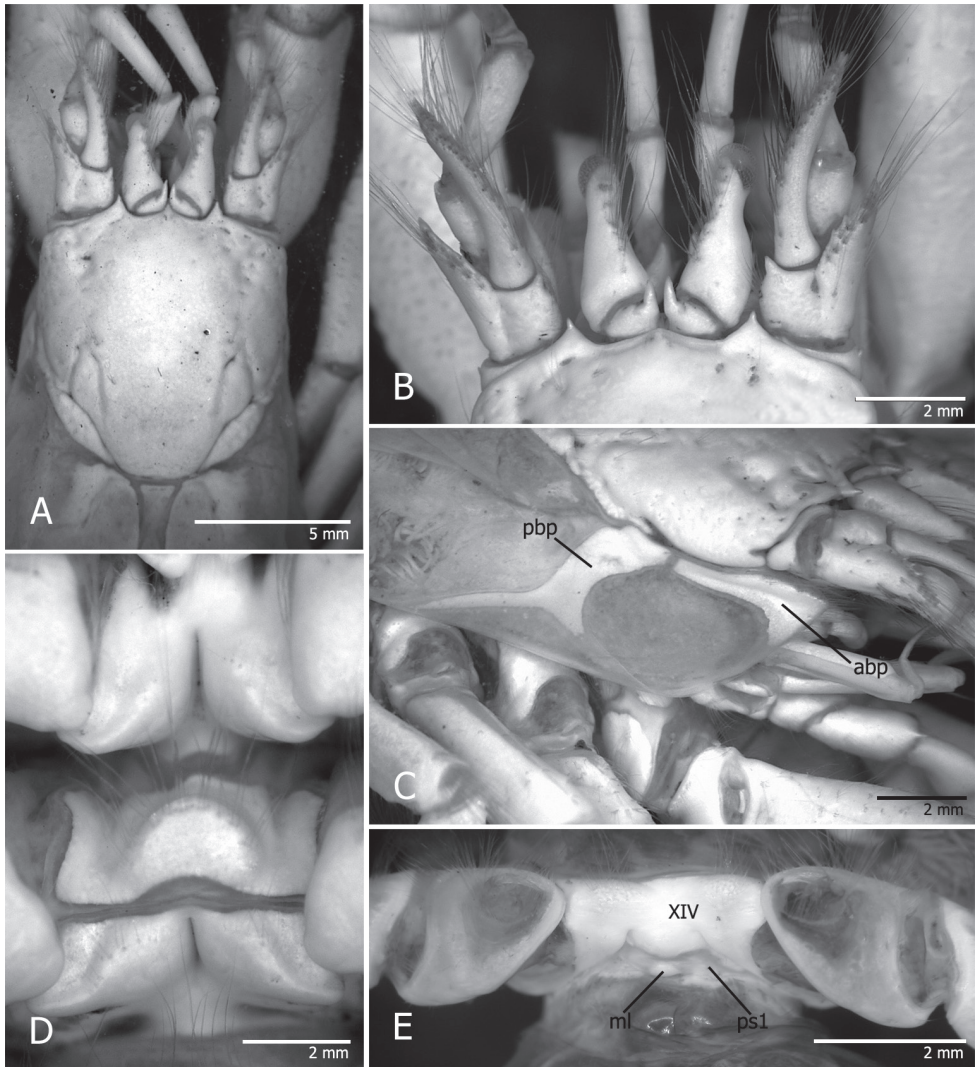


Figure 1. *Tomopaguropsis abkinpechensis* sp. n.: **A** holotype male 8.9 mm (EPC201310) **B–E** paratype male 8.1 mm (USNM 12376795) **A** Shield, cephalic appendages and anterior portion of posterior carapace, dorsal **B** anterior portion of shield, and cephalic appendages, dorsal **C** right branchiostegite, and portions of shield, cephalic appendages and first to fourth pereopods **D** sternites XI and XII (second and third pereopods), ventral **E** coxae of fifth pereopods, sternite XIV (fifth pereopods), and sternite of first pleonal somite, ventral. Stippled areas in A indicate membranous condition. Abbreviations: abp, anterior branchiostegal plate; pbp, posterior branchiostegal plate; ml, calcified median lobe; ps1, first pleonal somite.

Antennules (Fig. 2A) relatively robust, exceeding distal margin of corneas by one-fifth length of penultimate segment. Ultimate segment about one-fourth its length longer than penultimate, with scattered setae dorsally. Basal segment with strong laterodistal spine. Ventral flagellum with 8–12 articles.

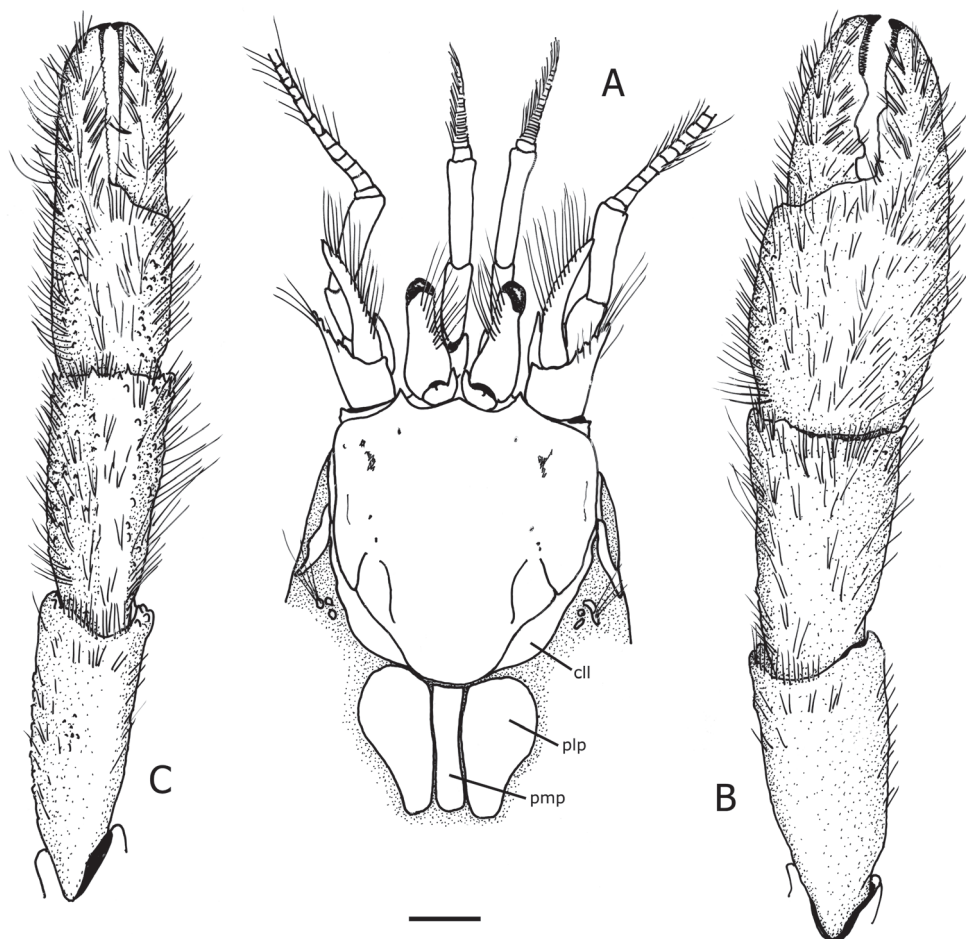


Figure 2. *Tomopaguropsis abkinpechensis* sp. n. paratype male, 8.1 mm (USNM 12376795). **A** shield, cephalic appendages, and portion of posterior carapace showing dorsal plates, dorsal **B** right cheliped, dorsal **C** left cheliped, dorsal. Scale: 2 mm. Abbreviations: cll, carapace lateral lobes; pmp, posteromedian plate; plp, posterolateral plates.

Antennal peduncles (Fig. 2A) long, exceeding distal margins of corneas by full length of fifth segment. Fifth and fourth segments unarmed, sparsely setose. Third segment with strong ventromesial spine. Second segment with dorsolateral distal angle prominently produced, with long setae dorsomesially, and terminating in strong spine with 3 or 4 small spines mesially. First segment with small spine on lateral face distally. Acicle exceeding distal margin of corneas by about half length of acicle, reaching to about midpoint of fifth antennal segment; terminating in minutely bifid spine; with dorsomesial row of long bristle-like setae extending to tip of acicle. Flagellum exceeding chelae, densely setose, with setae 2–8 flagellar articles in length.

Mandible with edge of incissor process weakly sinuous, sharp, chitinous. Maxillule with external lobe slender, straight, internal lobe with 1 or 2 long bristles. Maxilla with

endopodite not exceeding distal end of scaphognathite. First maxilliped with endopodite not exceeding distal margin of exopod. Second maxilliped without distinguishing characters. Third maxilliped with merus and carpus each armed with small dorsodistal spine; ischium with crista dentata consisting of about 15 small, subequal corneous teeth, with 1 accessory tooth (or as in holotype, with 2 teeth on one side); coxa with 2 sharp mesial teeth. Sternite IX (of third maxillipeds) with sharp spine on each side of midline.

Chelipeds not markedly asymmetrical, subequal in length; carpi and chela with dense, long bristle-like setae on dorsal surfaces, setae less dense and present only on distal two-thirds of ventral surfaces. Right cheliped (Fig. 2B) with fingers having numerous tufts of setae on dorsal surfaces, much less numerous on ventral surfaces, each finger terminating in inwardly curved, sharp corneous tip, armed with small blunt spines on dorsal surfaces basally and on lateral and mesial faces; cutting edges each consisting of fused corneous teeth on distal third, and 2 large, unequal rounded, calcareous teeth on proximal two-thirds, with additional smaller calcareous tooth on fixed finger. Right chela dorsal surface with scattered small spines, lateral and mesial margins rounded, with dorsomesial margin armed with irregular rows of small blunt or sharp spines; ventral face smooth. Carpus smooth except for few small blunt spines on dorsomesial margin distally, and distinct dorsodistal spine near distal margin; ventral surface smooth. Merus nearly naked, with row of setae on dorsodistal margin; smooth except for distal spine on ventromesial margin, and small, well-spaced blunt spines on ventral surface. Ischium unarmed except for ventromesial row of setae and irregular row of small blunt spines or tubercles on ventral surface.

Left cheliped (Fig. 2C) similar in setation and armature to right, except carpus with 3–5 sharp spines on dorsodistal margin.

Ambulatory legs or pereopods 2 and 3 (Fig. 3A–D) with dense, bristle-like setae or tufts of bristle-like setae, on dorsal and ventral margins of meri, carpi, propodi and dactyls, setae arranged in short transverse rows on dorsal margins of meri, carpi and propodi, denser on propodi. Dactyls broadly curved, each about 1.8 times as long as propodi, terminating in sharp corneous claw, and armed with 12–20 small corneous spinules on ventromesial margin; with row of bristle-like setae on ventromesial margin arranged in short transverse or oblique rows. Propodi through ischium unarmed except for: bristles and small dorsodistal spine on each carpus, and also merus of first ambulatory leg (pereopod 2), irregular row of small spines on ventral margin of merus of first ambulatory leg, and row of small spines on ischium of first ambulatory leg; ischium of second ambulatory leg (pereopod 3) with ventral margin lacking spines but with row of setae.

Pereopod 4 (Fig. 3E) weakly semi-chelate, with long, bristle-like setae dorsodistally on merus, and on dorsal margins of carpus, propodus and dactyl. Dactyl subtriangular, terminating in sharp, corneous claw, lacking preungual process; with ventrolateral row of minute, fused corneous teeth. Propodal rasp consisting of 2 rows of lanceolate corneous scales distally, 3 rows proximally.

Pereopod 5 chelate. Propodal rasp well developed, occupying nearly half of lateral face of propodus.

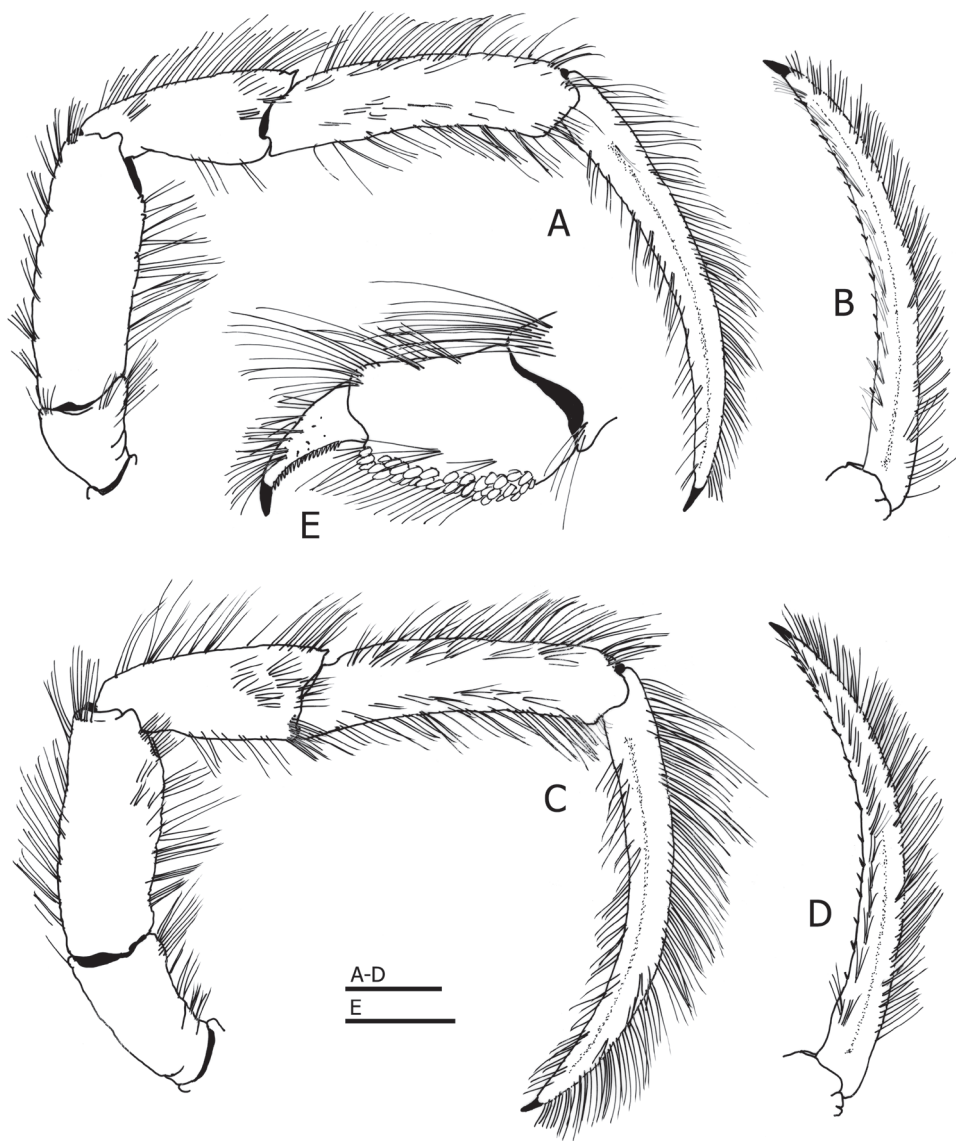


Figure 3. *Tomopaguropsis abkinpechensis* sp. n. paratype male, 8.1 mm (USNM 12376795). **A** right first ambulatory leg (pereopod 2), lateral **B** dactyl of same, mesial **C** right second ambulatory leg (pereopod 3), lateral **D** dactyl of same, mesial **E** propodus and dactyl of left pereopod 4, lateral. Scales: 2 mm for **A–D**, 1 mm for **E**.

Sternite XII (Fig. 1D) distinctly divided into anterior and anterior portions by membranous hinge. Anterior portion with semi-subcircular, setose lobe.

Sternite XIV (pereopod 5) weakly subdivided anteriorly into 2 setose lobes, with low posteromedian rounded ridge (Fig. 4C).

Pleon with first somite not fused to last thoracic somite. First somite with tergite consisting of pair of small calcareous plates anteriorly and partially calcified posterior portion (Fig. 4B); sternite calcified, with median lobe (Figs 1E, 4C).

Uropods strongly asymmetrical. Telson (Fig. 4D) nearly symmetrical, longer than broad; with distinct lateral indentations separating anterior and posterior portions; posterior lobes separated by small, shallow V-shaped sinus (more visible in holotype male 8.9 mm), distal margins of posterior lobes armed with small, mostly blunt spines with corneous tips.

Male with paired gonopores, each with slightly protruding vas deferens; lacking pleopods 1; pleopods 2–5 present on left side, biramous. Female unknown.

Etymology. The species name is derived from the Mayan “Ah-Kin-Pech” (meaning “place of snakes and ticks”), given by that civilization to a settlement where the city of Campeche, Mexico, is now located. The Mayan name was hispanicized and used for the modern city and adjacent Campeche Bank, in the vicinity of which this new species was collected.

Distribution. So far known only from the southwestern Gulf of Mexico, off the Campeche Bank; 780 to 827 m.

Habitat. Gastropod shells.

Variations. In the holotype male, the rostrum terminates in a sharp spine whereas in the paratype the rostrum terminates bluntly (Fig. 1A, B). The carpus of the right cheliped is more spinose than the paratype, having a dorsodistal margin armed with a distinct mesial spine and four small blunt spines laterally, the dorsomesial margin has irregular row of five distinct spines increasing in size distally and surrounded by irregularly placed small, blunt spines.

Affinities. This new species is curiously more similar morphologically to a congener from Indonesian waters, *Tomopaguropsis crinita*, than to the other only known congener from the western Atlantic, *T. problematica*. In the new species and *T. crinita*, the ocular peduncles diminish in width distally, and corneas are reduced or weakly dilated; the chelipeds and ambulatory legs are covered with dense, long bristle-like setae most frequently arranged in tufts, but otherwise are unarmed or at most with scattered small tubercles; and males lack paired pleopods 1 (at least in the known male specimens of both species).

Remarks. While this new species can be placed in *Tomopaguropsis* as currently defined (McLaughlin 1997, 2003), it is unusual and differs from other congeners in the development of calcified structures on the branchiostegite, posterior carapace, and pleon, at least based on the only two known male specimens. On the branchiostegite, all species of *Tomopaguropsis* have a narrow, calcified anterodorsal plate, but in *T. abkinpechensis* sp. n. there is also a narrow, calcified posterior plate that curves down following the sulcus verticalis and bifurcates ventrally (Figs 1C, 4A). In the new species, the posterior carapace has three calcified, well developed dorsal plates anteriorly (Fig. 2A): one dorsomedian or (“posteromedian plate”), and two dorsolateral (“posterolateral plates”). Also, in *T. abkinpechensis* sp. n., the first pleonal somite is not fused to the last thoracic somite, has a completely calcified sternite with a median lobe, and a tergite with a pair

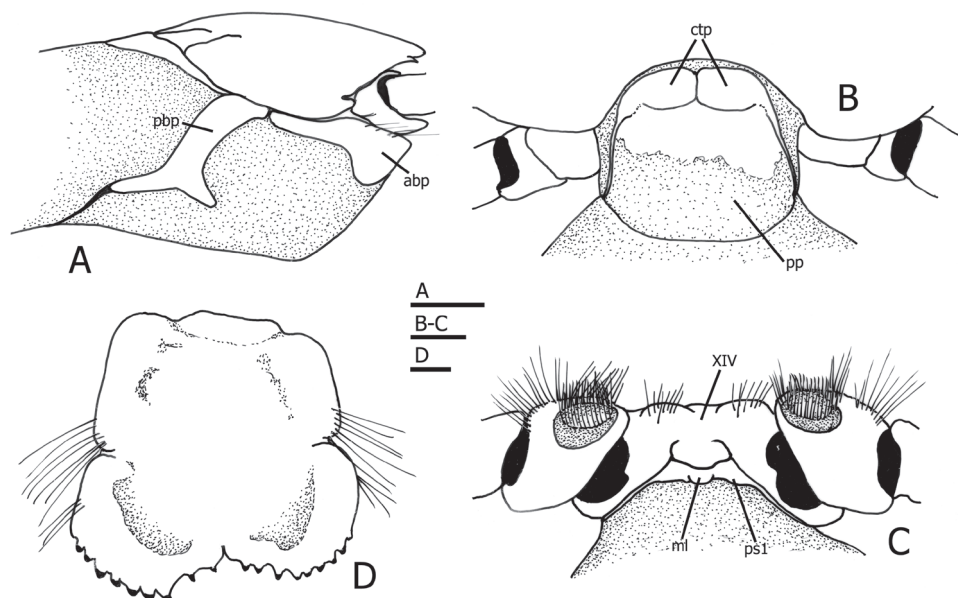


Figure 4. *Tomopaguropsis ahkinpechensis* sp. n. paratype male, 8.1 mm (USNM 12376795). Right side of carapace with shield, branchiostegite and anterior portion of posterior carapace, lateral **B** tergite of first pleonal somite, dorsal (up is anterior) **C** sternite XIV, coxae and gonopores of pereopods 5, and sternite of first pleonal somite (up is anterior). Abbreviations: ctp, calcareous tergal plates; pp, posterior portion; abp, pbp, ml and ps1 as in Fig. 1. Stippled areas in **A**, **B**, **C** indicate membranous condition. Scales: 2 mm for **A**, 1 mm for **B**, **C**, and 0.5 mm for **D**.

of fully calcified anterior plates and partially calcified posterior portion (Fig. 4B, C). The sternite of the first pleonal somite in *T. ahkinpechensis* sp. n. is similar to that of *T. crinita* in having a median lobe, but in *T. crinita* the sternite is fused to the last thoracic somite and not as strongly calcified as in *T. ahkinpechensis* sp. n.. The unique morphology of the branchiostegite and first pleonal somite in *T. ahkinpechensis* sp. n., could well justify the placement of this new species, and possibly *T. crinita* as well, in a separate new genus. Given that only two specimens of a single sex of this new species, and only four of *T. crinita*, are known, it is best to wait for additional material or obtain molecular data, in order to better evaluate whether these characters reflect or not the evolution of a separate clade that could justify their placement in a new genus.

The only two known male specimens of *Tomopaguropsis ahkinpechensis* sp. n. lack pleopods 1. As noted by McLaughlin (1997), male paired pleopods 1 could possibly be a variable condition in species of *Tomopaguropsis*. McLaughlin (1997) placed her two species *T. crinita* and *T. miyakei* in *Tomopaguropsis*, despite the absence of paired pleopods 1 in males of the former and that males of the latter were unknown. The presence of pleopods 1 in males was one of the main characters used by Alcock (1905) when he established the genus *Tomopaguropsis* for his *T. lanata* and A. Milne-Edwards and Bouvier's (1893) *Eupagurus ?problematicus* (= *T. problematica*, with spelling corrected).

McLaughlin (1997) noted that A. Milne-Edwards and Bouvier did not mention male pleopods 1 in the description of their taxon, and presumed that Alcock's assignment of *E. ?problematicus* to *Tomopaguropsis* was based on remarks by A. Milne-Edwards and Bouvier's that implied the presence of pleopods 1 in *E. ?problematicus*. In order to determine whether or not males of that species had paired pleopods 1, McLaughlin (1997) examined male specimens of *T. problematica* in museum collections and found them all to lack paired pleopods 1. However, we have examined one specimen (USNM 103420, 3.9 mm, from off Honduras, Caribbean Sea) which has paired pleopods 1 present and both male (paired) and female (unpaired right) gonopores, lending support to McLaughlin's assertion that male paired pleopods 1 may be a variable condition (possibly the result of parasitic feminization) in at least two species of *Tomopaguropsis*, *T. lanata*, and now *T. problematica*.

There is a striking similarity in sternite XII (of third pereopods) and first pleonal sternite and tergite of *T. ahkinpechensis* sp. n. with the two species of the family Pylojacquesidae (*Pylojacquesia colemani* McLaughlin & Lemaitre, 2001, and *Lemaitreopsis holmi* McLaughlin, 2007). In the new species and the two pylojacquesids, the anterior and posterior portions of sternite XII are distinctly separated by a membranous "hinge"; and the first pleonal somite has a pair of calcified plates anteriorly on the tergite, and a median lobe (in *T. ahkinpechensis* sp. n.) or posteriorly directed projection (in Pylojacquesidae). The similarity of these unusual characters conceivably can be interpreted as evidence of a close shared ancestry between *Tomopaguropsis*, as a member of the Paguridae, and the Pylojacquesidae, a phylogenetic relationship previously suggested by McLaughlin et al. (2007) and McLaughlin (2007). A full phylogenetic evaluation of *Tomopaguropsis* and its five species, however, must await the study and discovery of additional specimens, ideally combined with genetic analyses.

When McLaughlin (2003) updated the generic diagnosis of *Tomopaguropsis* she stated that a preungual process was absent in species of this genus, even though she (McLaughlin 1997) had previously reported the presence of a prominent preungual process in *T. miyakei*. Furthermore, examination of USNM specimens has shown that a preungual process is also present in *T. problematica*.

Key to species of *Tomopaguropsis*

- 1 Ocular peduncles decreasing in width distally, corneas not dilated; antennal peduncles distinctly exceeding distal margins of corneas by one-third or more length of fifth antennal segment..... **3**
- Ocular peduncles not decreasing in width distally, subcylindrical, corneas moderately dilated; antennal peduncles not exceeding or at most slightly exceeding distal margins of corneas **2**
- 2 Ventral margins of dactyls of ambulatory legs (pereopods 2, 3) armed with corneous spines; posterior lobes of telson nearly symmetrical, separated by V-shaped median cleft ***T. miyakei* McLaughlin, 1997** (Indonesia)

- Ventral margins of dactyls of ambulatory legs (pereopods 2, 3) unarmed, lacking corneous spines; posterior lobes of telson asymmetrical, separated by narrow slit...
..... ***T. problematica* (A. Milne-Edwards & Bouvier, 1893)** (Western Atlantic)
- 3 Dorsal surfaces of chelae distinctly spinulose.....
..... ***T. lanata* Alcock, 1905** (Indian Ocean)
- Dorsal surfaces of chelae not spinulose or at most with scattered small tubercles ...4
- 4 Branchiostegite with narrow, calcified posterior plate curving down, following sulcus verticalis, and bifurcated ventrally (Figs 1C, 4A); propodus of pereopod 4 longer than high (Fig. 3E)
..... ***T. abkinpechensis* sp. n.** (Gulf of Mexico)
- Branchiostegite lacking narrow, calcified posterior plate; propodus of pereopod 4 about as long as high..... ***T. crinita* McLaughlin, 1997** (Indonesia)

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Ingolfiella maldivensis sp. n. (Crustacea, Amphipoda, Ingolfiellidae) from coral reef sand off Magoodhoo island, Maldives

Ronald Vonk^{1,2}, Damiá Jaume³

1 Naturalis Biodiversity Center, P. O. Box 9517, 2300 RA Leiden, The Netherlands **2** Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Amsterdam 1098 XH, The Netherlands **3** Instituto Mediterráneo de Estudios Avanzados, IMEDEA (CSIC-UIB), C/ Miquel Marqués 21, 07190 Esporles, Balearic Islands, Spain

Corresponding author: Ronald Vonk (ronald.vonk@naturalis.nl)

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Abstract

A new species of marine interstitial wormshrimp, *Ingolfiella maldivensis*, is described from coral sand on the inner and outer reef off Magoodhoo island, Faafu atoll, Maldives. Six females were found and compared to other species from the Maldives and those bordering the Indian Ocean and beyond. Morphological resemblance ties it to a species from the Caribbean island of Curaçao. Both species are found in shallow sublittoral interstitial spaces.

Keywords

Taxonomy, sublittoral, interstitial habitat, dive sampling, atolls, Indian Ocean

Introduction

The Maldiv Islands (Central Indian Ocean) consist of a 800-km long string of 22 atolls containing an extensive coral reef system topped by over a thousand islands (Coleman 2000; Spalding et al. 2001). During field work off Magoodhoo island in the Faafu atoll, republic of Maldives, six female specimens of the rare amphipod family Ingolfiellidae were

found. Ingolfiellids are known to live strictly subterranean in a wide variety of aquatic habitats; from the ocean floor to shallow marine interstitial sand habitats through to caves and brackish and fresh continental groundwater (Stock 1977; Vonk and Schram 2003).

The first Maldives Coral Reef Biodiversity Workshop located at MARHE Centre in Magoodhoo (May 2014) enabled sampling by use of SCUBA and access to a wide variety of suitable habitats for reef coral rubble inhabitants. Previously, only two other specimens of representatives of the family had been reported from the Maldives (Ruffo 1966).

Although their numbers are mostly low, the presence of vermiform and interstitial ingolfiellids or wormshrimps (Vonk and Nijman 2006) is expected for all tropical reef sand environments. As they have no free-swimming larvae in the water column and a low egg production (Siewing 1963) their capacity for long distance dispersal is presumably quite limited. Geographically separated populations show subtle but constant morphological differences and, in the absence of molecular phylogenetic comparisons, are considered to represent different species.

In this paper we describe *Ingolfiella maldivensis* sp. n. and discuss relations to other species.

Material and methods

The six specimens of the new species were collected from two different sites (Fig. 5) by SCUBA diving between 2–25 m depth. A plastic probing tube of 12 cm and a diameter of 2.5 cm was drilled by hand into the sand at selected places where the top layer of coarse reef sand is thick enough as to allow vertical to slightly skewed probing. The top of the tube contains a small hole for escape of excess water. Then the tube is carefully removed, with the top closed and so creating a vacuum suction that prevents the sediment from falling out. After this a lid is quickly placed over the opening.

The samples were sorted in the Italian field station of the Milano-Bicocca Marine Research and High Education Centre (MARHE) under a dissecting microscope and transferred to 96% ethanol. Before study, specimens were treated with lactic acid to soften the cuticle and remove internal tissues to facilitate observation. Photo of entire animal (Fig. 1) was made with a Zeiss Axio Imager M2 microscope using differential interference contrast (DIC). Drawings were prepared using a camera lucida on an Olympus BX 53 microscope equipped with DIC. Specimens and appendages preserved on slides were mounted in Faure's medium and the coverslips sealed with transparent nail varnish. Body measurements were derived from the sum of the maximum dorsal dimensions (including telescoped portions) of head, pereionites, pleosomites and urosomites, and exclude telson length. Following Watling (1989), the term "spine" in descriptions is restricted for rigid armature elements with a hollow central core that do not articulate basally to the body integument.

Taxonomy

Order AMPHIPODA Latreille, 1816

Suborder INGOLFIELLIDEA Hansen, 1903

Family INGOLFIELLIDAE Hansen, 1903

Genus *Ingolfiella* Hansen, 1903

Ingolfiella maldivensis sp. n.

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Figs 1–4

Material examined. One specimen, RMNH.CRUS.P.264, female paratype 1.85 mm, at station ‘Blu Cove’, 6 May 2014, depth 15 m, N3°05'37.8", E72°57'59.4". Five specimens: RMNH.CRUS.P.265, undissected female holotype 1.80 mm (Fig. 1); RMNH.CRUS.P.266, female paratype 1.55 mm; RMNH.CRUS.A.5054, female paratypes, at Dharamboodhoo reef, 11 May 2014, depth 20 m., N3°03'30.5", E72°55'29.6". All collected by R. Vonk. Specimens are stored in the Crustacea collection of Naturalis Biodiversity Center, Leiden.

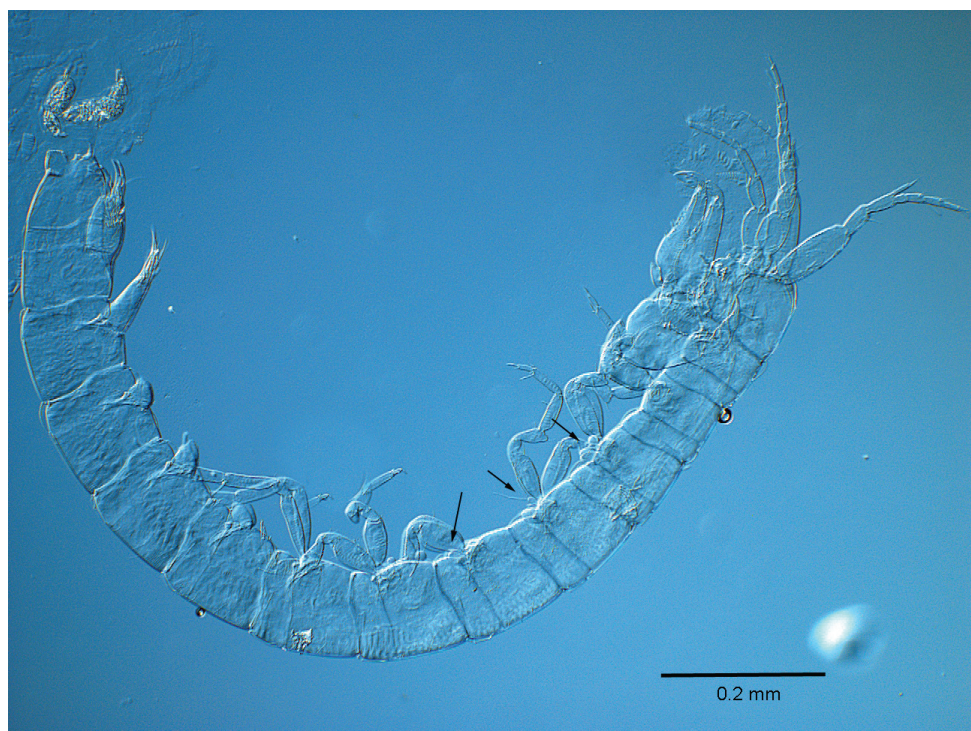


Figure 1. *Ingolfiella maldivensis* sp. n., holotype female 1.80 mm (including telescoped body somites). Arrows point to gills and oostegites on the third and fourth pereopods, and on gills on the fifth pereopod.

Diagnosis. Lateral lobes on frontal margin of the head present. Dactyls of gnathopods armed with four javelin lancet shaped bladelike spines along posterior margin. Palm of G2 angle robust seta bifid; posteromedial surface of carpus lacking broad triangular spine. Medial surface of protopod of U2 with three denticle combs. Unguis of P3–P4 with four denticles; that of P5–P7 bifid. PL1–PL3 present and of similar form. Oostegites on P3–P4.

Etymology. The new species is named after the group of islands where it was found, in the Republic of the Maldives.

Description. Body elongate, cylindrical, without coloration, transparent to milky white (Fig. 1). *Head* with frontal margin nearly straight, no sinus visible, cephalic lobe placed a little backwards from the frontal margin (Fig. 2A).

Antennule (Fig. 2B), peduncle article 1 robust, slightly inflated, articles 2 and 3 of equal length. Flagellum 4-articulate, longer than peduncle articles 2–3 combined; proximal article unarmed and short, other three articles of equal length; articles 2–4 each provided with aesthetasc, aesthetascs progressively shorter towards distal. Accessory flagellum 3-articulate, shorter than two proximal articles of main flagellum combined.

Antenna (Fig. 2C) slightly shorter than antennule; gland cone short, hardly protruding dorsomedially; protopodal articles 3–5 inflated, especially the third one, fourth segment with two long setae on posterior margin; Flagellum 5-articulate, shorter than protopodal articles 4–5 combined.

Labrum (Fig. 2D) and paragnaths (not figured) ordinary, latter lacking inner lobes.

Mandibles with molar process non-tritulative, spiniform and not serrated. *Right mandible* (Fig. 2E) with 6-denticulate incisor; spine row with three short, stubby, finely serrated elements. *Left mandible* (not figured) with spine row comprising two blunt finely ribbed elements.

Maxillule (Fig. 2F) coxal endite [= inner lobe] with two simple setae; basal endite [= outer lobe] with six robust setae of which two bicuspidate, one 3-cuspidate, one long and 5-cuspidate, one short, broad and 3-cuspidate, and one – the innermost – crooked and 4-cuspidate; endopod (=palp) 2-segmented, distal segment with two long slender setae.

Maxilla (Fig. 2G) with short, subequal blunt plates, outer one with five distal setae, inner one with four distal setae; two out of five setae on outer plate sparsely setulose.

Maxilliped (Fig. 2H) basal endite rudimentary, with one simple seta; merus with one simple seta on outer margin; propodus with two single simple seta on opposite margins; dactylus slender, with two distal setae, and long unguis.

Coxal gills (Fig. 1) present on P3–P5, rounded to ovoid. *Oostegites* (Figs 1, 3B') on P3–P4, short, subrectangular and shorter than corresponding coxal gill, each with one long slender seta.

Gnathopod 1 (Fig. 2I) carpo-subchelate, carpus almost 3 times as long as broad and exceptionally slender and elongated toward the tip, with three short, bifid flagellate robust setae along lateral side of palm margin, one robust seta on palm angle, and one short stout simple seta and broad triangular spine on medial surface of segment as

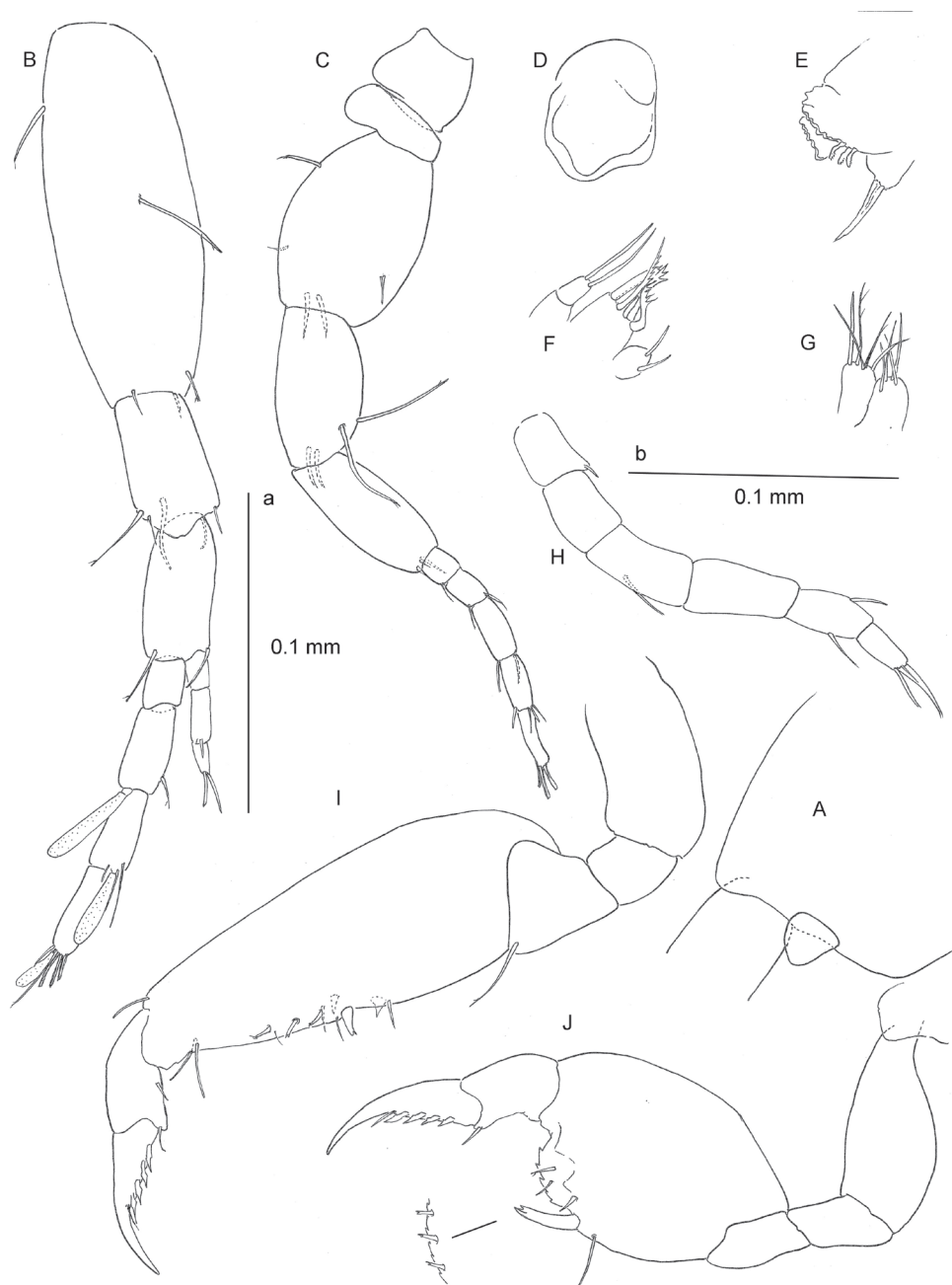


Figure 2. *Ingolfiella maldivensis* sp. n., holotype female 1.80 mm **A** cephalic lobe **B** antennule **C** paratype female 1.85 mm, antenna **D** paratype female 1.55 mm, labrum **E** right mandible with incisor and molar process **F** maxillule **G** maxilla **H** maxilliped **I** paratype 1.85 mm, right gnathopod 1, medial **J** right gnathopod 2, medial (inset: palm margin of holotype 1.80 mm).

figured; palm margin slightly convex and smooth; dactylus with four slender stalked-lanceolate bladellike denticles along posterior margin.

Gnathopod 2 (Fig. 2J) carpo-subchelate, carpus massive, shorter and broader than carpus of G1; palm margin strongly convex, clearly serrated, lined up with three short, bifid flagellate robust setae along lateral side; palm angle marked by stout, slightly curved bifid robust seta; medial surface of segment with short, simple robust seta that varies between individuals in width, however it is not a broad, strong triangular spine; posteromedial surface of carpus with excavation apparently to accommodate distal portion of unguis; dactylus with four lanceolate bladellike denticles along posterior margin.

Pereiopods 3–4 (Fig. 3A, B) subequal except for slightly longer propodus in P4; dactylus elongate, with two simple setae at the base of the unguis; unguis slender and with four fine denticles on tip.

Pereiopods 5–7 (Fig. 3C–E) progressively longer towards posterior; basis of P5–P6 broad, that of P7 slender. P7 with one of distal armature elements on distolateral angle of carpus modified into a crooked comb-like seta. Dactylus of P5–P6 short, that of P7 longer. Unguis of P5 bifid but not so outspoken as in P6–P7. Gill present on P5.

Pleopods 1–3 (Fig. 3F) subtriangular.

Uropod 1 (Fig. 4A) protopod subrectangular; exopod much shorter than endopod, acuminate, with short robust seta terminally and tiny simple seta placed subdistally; endopod with short terminal spine plus row of three stout triangular robust setae subdistally; nine simple setae disposed on segment as figured.

Uropod 2 (Fig. 4B) protopod bearing three oblique combs of mostly bifid spines on medial surface; two most proximal combs including one long seta; rami tapering, each with strong terminal simple seta clearly articulating at base, exopod stouter and slightly shorter than endopod.

Uropod 3 (Fig. 4C) small and uniramous, protopod triangular, with two setae flanking the short exopod; exopod with long apical seta.

Telson (Fig. 4C) entire and thick, fleshy, with one plumose seta distomarginally at each side.

Remarks. Previous knowledge on the ingolfiellids from the Maldives was restricted to specimens collected during the Xarifa Expedition 1957–1958. These came from washings of the coral *Favites* sp. (Ruffo 1966). They were described as *Ingolfiella xarifae* Ruffo, 1966 and came from Rasdu atoll, some 130 kilometers north of the Faafu atoll where specimens of the present species were found. *Ingolfiella xarifae* differs from the rest of *Ingolfiella* species by having three denticles on the posterior margin of the dactylus of the first gnathopod, and four on the second (see Vonk and Jaume 2014). They also have a trifid unguis on the third and fourth pereiopod, and a broad triangular spine on the posteromedial surface of the carpus in the second gnathopod. These features set them clearly apart from *I. maldivensis* sp. n. which has four denticles on both gnathopod dactyli, multidenticulate claws and no triangular spine on the carpus of the second gnathopod.

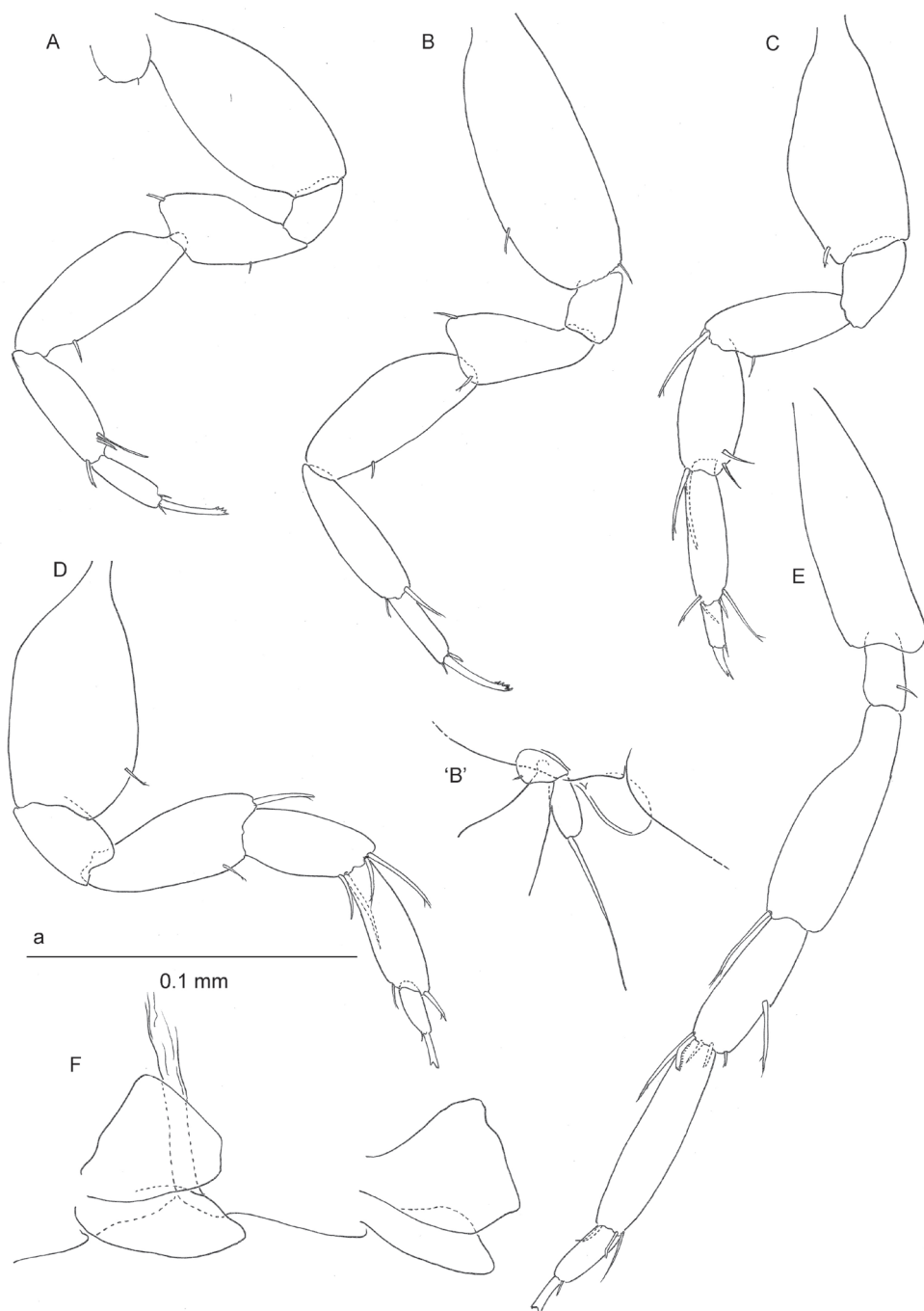


Figure 3. *Ingolfiella maldivensis* sp. n., paratype female 1.85 mm **A** pereiopod 3 **B** pereiopod 4 **B'** holotype female 1.80 mm oostegite and gill on pereiopod 4 **C** paratype female 1.55 mm pereiopod 5 **D** paratype female 1.85 mm pereiopod 6 **E** pereiopod 7 **F** pleopods 2 and 3.

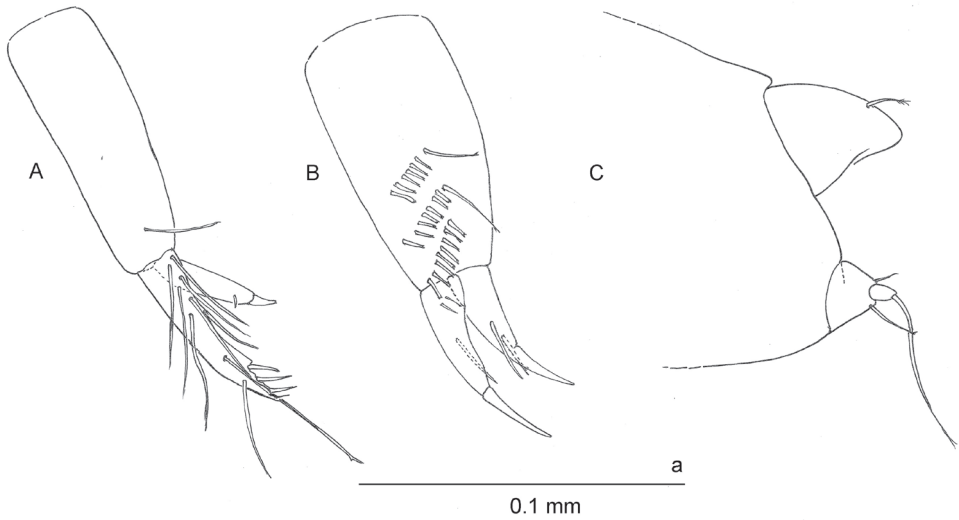


Figure 4. *Ingolfiella maldivensis* sp. n., paratype female 1.85 mm **A** uropod 1 **B** paratype female 1.55 mm uropod 2 **C** paratype female 1.85 mm uropod 3 and telson.

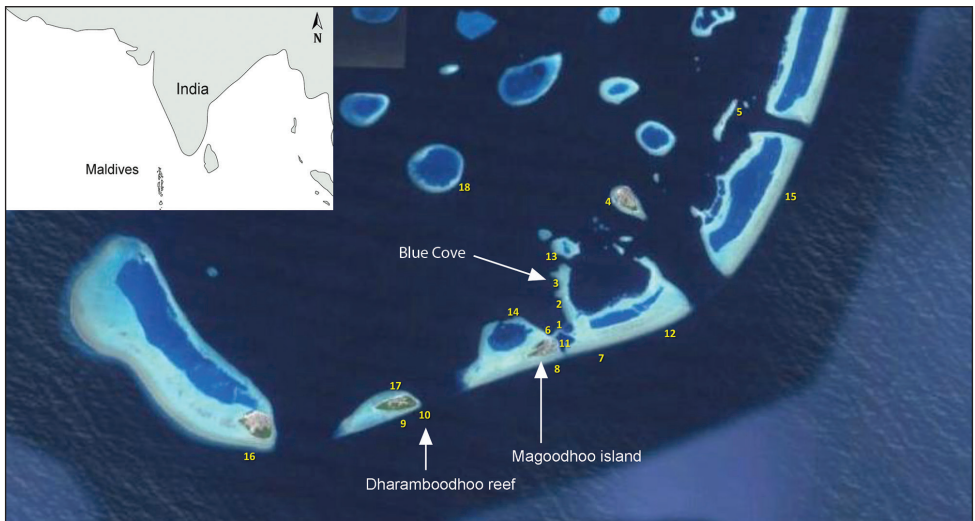


Figure 5. Map of dive sites around Magoodhoo island, Faafu atoll, Republic of the Maldives (Modified from Montano et al. 2014). Stations 3 (inner reef) and 10 (outer reef) contained ingolfiellid amphipods.

A comparison of fourteen easy to distinguish characters between members of the genus *Ingolfiella* (45 species) was done by Vonk and Jaume (2014). The new species ranks next to a Caribbean species from comparable shallow sublittoral habitats off the coast of Curaçao, namely *I. quadridentata* Stock, 1979. Character states overlap entirely for the eight non-male-specific features of Vonk & Jaume's matrix, but other features differ. Thus, the basal endite of the maxilliped is small and barely developed in

I. maldivensis, but separate and as long as the ischium in *I. quadridentata*; the triangular spine on the posteromedial surface of carpus of the first gnathopod is lacking in *I. quadridentata*; the oostegites are crowned with one long seta in *I. maldivensis*, but have a 3-pronged distal margin in *I. quadridentata*; and the claw of the fourth pereopod is 4-denticulate in *I. maldivensis* but 7-denticulate in *I. quadridentata*.

Other species bordering the Indian Ocean include: *I. kapuri* Coineau & Rao, 1973, from the Andaman and Nicobar Islands in intertidal shell debris; *I. arganoi* Iannilli & Vonk, 2013 from Abd-al-Kuri Island, Socotra Archipelago in an anchialine pool; *I. quokka* Gallego-Martínez & Poore, 2003, from an intertidal sandy beach environment from the City of York Bay, Western Australia. All of these species differ sharply from *I. maldivensis* (see Vonk and Jaume 2014: table 1).

The recently described *I. botoi* Vonk & Jaume, 2014, from beach groundwater in the Gura Ici Islands, Molucca Sea, Indonesia (Vonk and Jaume 2014), shares more features with *I. maldivensis* than with the rest of the Indian Ocean species mentioned above. It can be remarked that the Maldives, forming the western rim, and the Moluccas, positioned in the middle, are both still part of one large Indo-Polynesian marine biogeographic province (Briggs and Bowen 2012).

Discussion

Repeated visits to the same island groups or to mainland karst areas have often revealed additional species each time a specific search for ingolfiellids was made. In other cases populations of the same species are spread over different islands. This was encountered in the Canary islands for the widely separated islands Hierro and Tenerife (Vonk and Sánchez 1991; Vonk and Jaume 2014). Yet also in that same Canary island group two other, different, species were found: *Ingolfiella similis* on Fuerteventura (Rondé-Broekhuizen and Stock 1987) and *Ingolfiella* sp. on Lanzarote (Wilkens et al. 2009). On the Philippines *I. alba* appears in littoral sands of more than one island (Iannilli et al. 2008) and remains the only species known from that large archipelago. But in the small Indonesian Gura Ici island group in the Molucca Sea two species appear in syntopy in the same beach groundwater spot (Vonk and Jaume 2014). After many years of sampling in the Caribbean islands of Aruba, Curacao, and Bonaire five species in diverse aquatic habitats such as marine sublittoral carbonate sands, brackish caves and terrestrial groundwater were recognized (Stock 1979).

These examples lead to the expectation that an ocean spanning, circumtropical continuum exists of populations gradually changing in minor morphological adaptations and converging in functional form toward their environment. Such convergence could explain why a sublittoral reef sand inhabiting form from the Caribbean is more similar to a form that lives in comparable micro-habitats in the Indian Ocean, than it is to a congener (*I. grandispina* Stock, 1979) found a few kilometers away in a brackish cave bottom with other functional requirements to form. This convergent development can be observed in the close morphological resemblance of *I. quadridentata* from

the Caribbean island of Curacao and the species, described in this study, *I. maldivensis*. They both come from sublittoral reef sands.

The Maldives have undergone dramatic sealevel changes (Aubert and Droxler 1992; Gischler et al. 2014). This has changed the islands from karstic, well emerged platforms with ample subterranean habitat types to the flat atolls of today (Schlager and Purkis 2013). Future discoveries of relicts of this subterranean diversification may reflect this geological past.

Acknowledgements

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Five new species of *Minettia* (*Minettiella*) (Diptera, Lauxaniidae) from China

Li Shi¹, Ding Yang²

1 College of Agronomy, Inner Mongolia Agricultural University, Hohhot, Nei Mongol 010019, China

2 Department of Entomology, China Agricultural University, Beijing 100193, China

Corresponding author: Li Shi (lishiagromyzid@gmail.com; lirui2003@imau.edu.cn)

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Abstract

Five species of *Minettia* Robineau-Desvoidy, 1830 from the South of China are described as new to science: *Minettia* (*Minettiella*) *bawanglingensis* sp. n., *M.* (*Minettiella*) *clavata* sp. n., *M.* (*Minettiella*) *plurifurcata* sp. n., *M.* (*Minettiella*) *spinosa* sp. n. and *M.* (*Minettiella*) *tianmushanensis* sp. n. *Minettiella elbergi* Shatalkin, 1996 and *Minettia japonica* Sasakawa, 1995 are treated as junior synonyms of *M.* (*Minettiella*) *dolabriforma* (Sasakawa & Kozánek, 1995). A key to five subgenera of *Minettia* and eleven species of *Minettia* (*Minettiella*) is presented.

Keywords

Minettiella, synonym, female terminalia, Oriental region

Introduction

The subgenus *Minettiella* Malloch, 1929, of the genus *Minettia* Robineau-Desvoidy, 1830, was erected for the type species *Lauxania atratula* Meijere, 1910, being glossy black, and having immaculate wings, yellow halteres, a katepisternum with a discal katepisternal seta, pubescent aristae, shining frons, a flat face, and mesonotum with 0–1+2–3 dorsocentral setae and 0–1+2–4 acrostichal setae, and most species having one to three pairs of strong acrostichal setae (Malloch 1929; Stuckenberg 1971).

Actually, all species have pruinosity on the mesonotum and abdomen (only the frons is shining black), so the so-called “glossy” black habitus is not correct.

Shatalkin (1996) had elevated the subgenus *Minettiella* to the genus level when he described *Minettiella elbergi* Shatalkin, 1996. Shatalkin (2000) discussed that its having genus rank was based on the specialized male genitalia and the above-mentioned diagnosis, and noted that the described species *Minettiella acrostichalis* (Sasakawa & Kozánek, 1995) was possibly a synonym of *Minettiella coracina* Shatalkin, 1993, and two described species *Minettiella elbergi* and *Minettia japonica* (Sasakawa, 1995) were possibly synonyms of *Minettiella dolabriforma* (Sasakawa & Kozánek, 1995) (Shatalkin 2000). We examined the male genitalia of some specimens from five subgenera of *Minettia* and found that the diversity of the male genitalia (that is, there are lots of many different forms among the species) exists in the three subgenera *Minettia*, *Minettiella* and *Plesiominettia* Shatalkin, 2000, which is more diversity of male genitalia than that in two subgenera *Frendelia* (Collin, 1948) and *Scotominettia* (Shatalkin, 2008) based on many examined specimens of five genera from the Palaearctic and Oriental regions. The diversity of the male genitalia in *Minettiella* is the same as that in *Minettia* and *Plesiominettia*. So we reject Shatalkin’s elevation of the subgenus *Minettiella* to the genus level and consider *Minettiella* as a subgenus *Minettiella*. Moreover, we compared the male genitalia *M. (Minettiella) elbergi* and *M. (Minettiella) japonica* and determined them to be junior synonyms of *M. (Minettiella) dolabriforma*. The color of the mid and hind tibiae and the ratio of height and length of the 1st flagellomere in *M. (Minettiella) coracina* Shatalkin are distinctly different from that in *M. (Minettiella) acrostichalis* (Sasakawa & Kozánek, 1995), so the species *M. (Minettiella) coracina* Shatalkin is considered to be a valid species.

The type specimen of *M. (Minettiella) atrata* (Meijere, 1910) was recorded in Jong (2000) as missing the male genitalia, but fortunately the description and diagnosis is adequate to separate it from other species.

In total, there are eleven known species of the subgenus *Minettiella* with six currently found in China (see Appendix for species checklist).

Materials and methods

The general terminology follows Gaimari and Silva (2010). Genitalia preparations were made by removing and macerating the apical portion of the abdomen in cold saturated NaOH for 6 hours. After examination, they were transferred to glycerine for examination and stored in a microvial on the pin below the specimen. Specimens examined were deposited in China Agricultural University, Beijing, China (CAUC).

The following abbreviations are used: *a*—anterior seta(e), *acr*—acrostichal seta(e), *ad*—anterior dorsal seta(e), *app*—apical posterior seta(e), *apv*—apical ventral seta(e), *av*—anterior ventral seta(e), *dc*—dorsocentral seta(e), *ia*—intra alar, *kepst*—katepisternal seta(e), *oc*—ocellar seta(e), *or*—fronto-orbital seta(e), *p*—posterior seta(e), *pd*—posterior dorsal seta(e), *prsc*—prescutellar seta(e), *pv*—posterior ventral seta(e).

Taxonomy

Species descriptions

Unless otherwise specified, the following seven species described below are characterized as follows: Head, thorax and abdomen black. Frons wider than long and parallel-sided. Face and parafacial flat with dense whitish gray pruinosity. Ocellar triangle black; *oc* developed, shorter than anterior *or*, anterior *or* reclinate, shorter than posterior *or*. Arista black with yellow at base. Scutellum black, with brown grayish pruinosity. All femora black or blackish brown. Wing slightly yellow, hyaline. Halter yellow.

Minettia (*Minettiella*) *atratura* (Meijere, 1924)

Figs 1–5, 31–32

Lauxania atratura Meijere, 1924: 49. Type locality: Indonesia (Sumatra).

Minettia (*Minettiella*) *atratura*: Malloch 1929: 26. Shewell 1977: 190. Shatalkin 1996: 147. Jong 2000: 32.

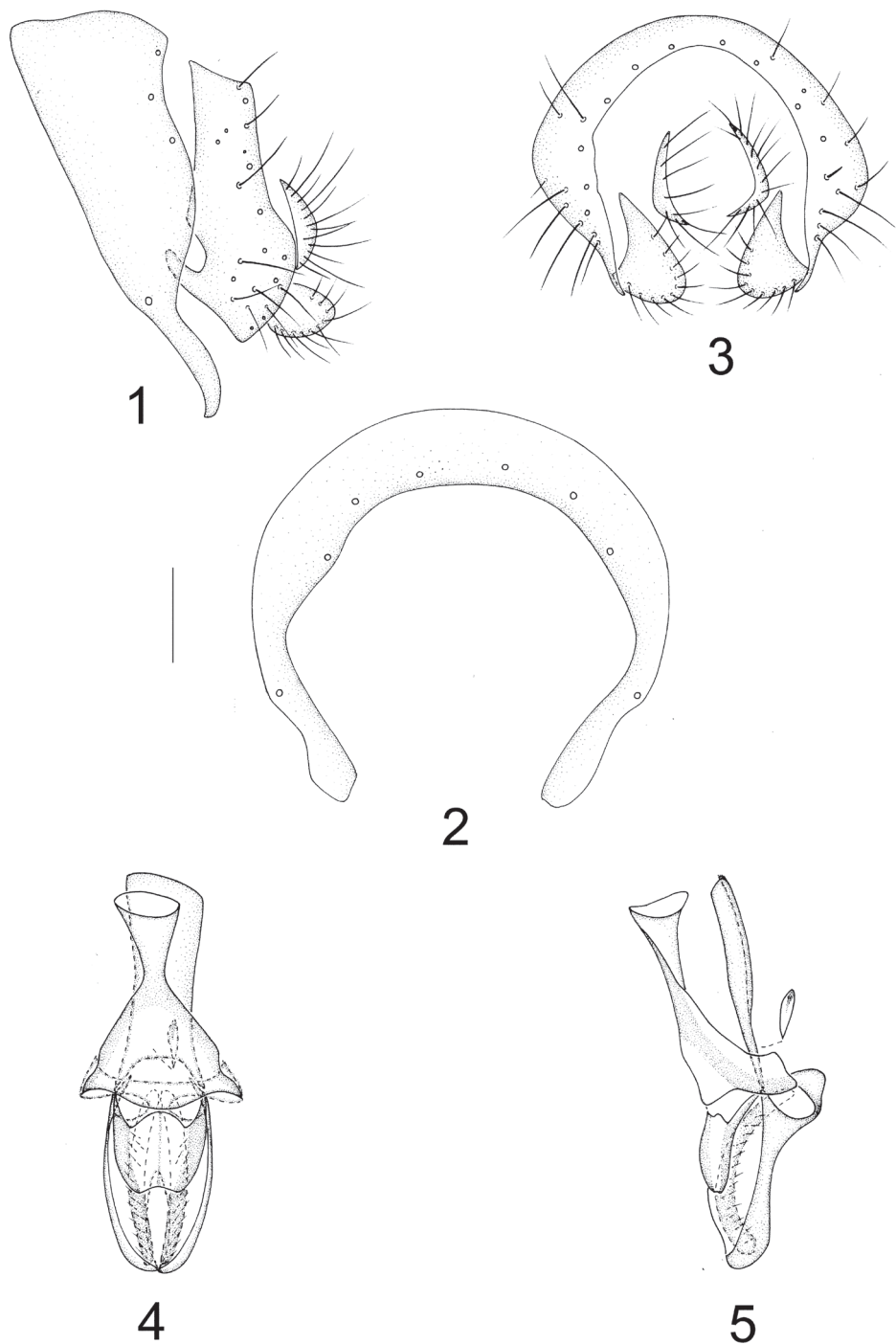
Material examined. 2 ♂♂, 1 ♀ (CAUC), CHINA, Hainan: Ledong, Jianfengling National Natural Reserve, Tianchi, 800 m, 18. v. 2006, Hui Dong; 1 ♂ (CAUC), CHINA, Hainan: Ledong, Jianfengling National Natural Reserve, Tianchi, 800 m, 18. v. 2006, Gang Yao.

Diagnosis. Mesonotum 1+3 *dc*, *acr* in 2 rows with 1+3 long *acr*. Fore tibia yellowish brown with yellow at base and black at apex, mid tibia yellow and hind tibia yellow with brown at apex; fore tarsi with basitarsus yellow on basal 3/4 and tarsomeres 2–5 brown, mid and hind tarsi with tarsomeres 1–2 dark yellow and tarsomeres 3–5 pale brown. Mid femur with 4 *a*.

Redescription. MALE. Body length 3.3–3.5 mm, wing length 3.4–3.5 mm. FE-MALE. Body length 3.8 mm, wing length 3.9 mm.

Head. Frons slightly concave with narrow yellow anterior margin. Gena about 1/4 eye height. Antenna scape and pedicel yellowish brown to brown, 1st flagellomere blackish brown with yellow at base and nearly 2.3 times longer than high; arista bare. Proboscis black with dark yellow at apex. Palpus black.

Thorax with brownish gray pruinosity. Mesonotum with 1+3 *dc*, *acr* in 2 rows with 1+3 long *acr* in front of *prsc* and one pair of *prsc* as long as 1st postsutural *dc*. Legs: fore tibia mostly yellowish brown with yellow at base and black at apex; mid tibia yellow and hind tibia yellow with brown at apex; fore tarsi with basitarsus yellow on basal 3/4 and tarsomeres 2–5 brown, mid and hind tarsi with tarsomeres 1–2 dark yellow and tarsomeres 3–5 pale brown. Fore femur with 4 *pv* and 6 *pd*, fore tibia with 1 long preapical *ad* and 1 short *apv*. Mid femur with 4 *a* and 1 *app*; mid tibia with 1 strong preapical *ad* and 1 strong *apv*. Hind femura with 1 preapical *ad*, and hind tibia with 1 weak preapical *ad* and 1 short *apv*. Wing with costa



Figures 1–5. *Minettia (Minettiella) atratula* (Meijere, 1924). Male. **1** syntergosternite and epandrium, lateral view **2** syntergosternite, anterior view **3** epandrial complex, posterior view **4** aedeagal complex, ventral view **5** aedeagal complex, lateral view. Scale bar = 0.1 mm.

with 2nd (between R_1 and R_{2+3}), 3rd (between R_{2+3} and R_{4+5}) and 4th (between R_{4+5} and M_1) sections in proportion of 6.7:1:1, *r-m* at middle of discal cell; ultimate and penultimate sections of M_1 in proportion of 1:1.1; ultimate section of CuA_1 about 1/6 of penultimate section.

Abdomen with sparse brownish gray pruinosity. Male genitalia (Figs 1–5): syntergosternite semicircular with three pairs of dorsal setulae, epandrium narrow basally and broad apically, with a deep concave on anterior ventral margin and a digitiform anterior process, triangular apically in lateral view; surstylus separated from epandrium, elliptical in lateral view but crescent-shaped in posterior view; hypandrium nearly Y-shaped; postgonite forming a complete sclerite, with a median ridge; aedeagus consisting of a pair of clavate inner sclerites with short setulae and a pair of dorsolateral concaves, rounded apically; height of aedeagal apodeme nearly as long as aedeagus and broad in ventral view. Female terminalia (Figs 31–32): sternite 8 with a brown U-shaped spot, spermathecae 2+1, elliptical.

Distribution. China (Hainan, Taiwan), Indonesia (Sumatra), Vietnam.

***Minettia* (*Minettiella*) *bawanglingensis* sp. n.**

<http://zoobank.org/2742238E-F11B-4A8C-BDEF-85B255376811>

Figs 6–10, 33–34

Type material. Holotype: ♂ (CAUC), CHINA, Hainan: Changjiang, Bawangling National Natural Reserve, Dong'er station, 1000 m, 24. v. 2007, Kuiyan Zhang. Paratype: 1♀ (CAUC), CHINA, Hainan: as holotype.

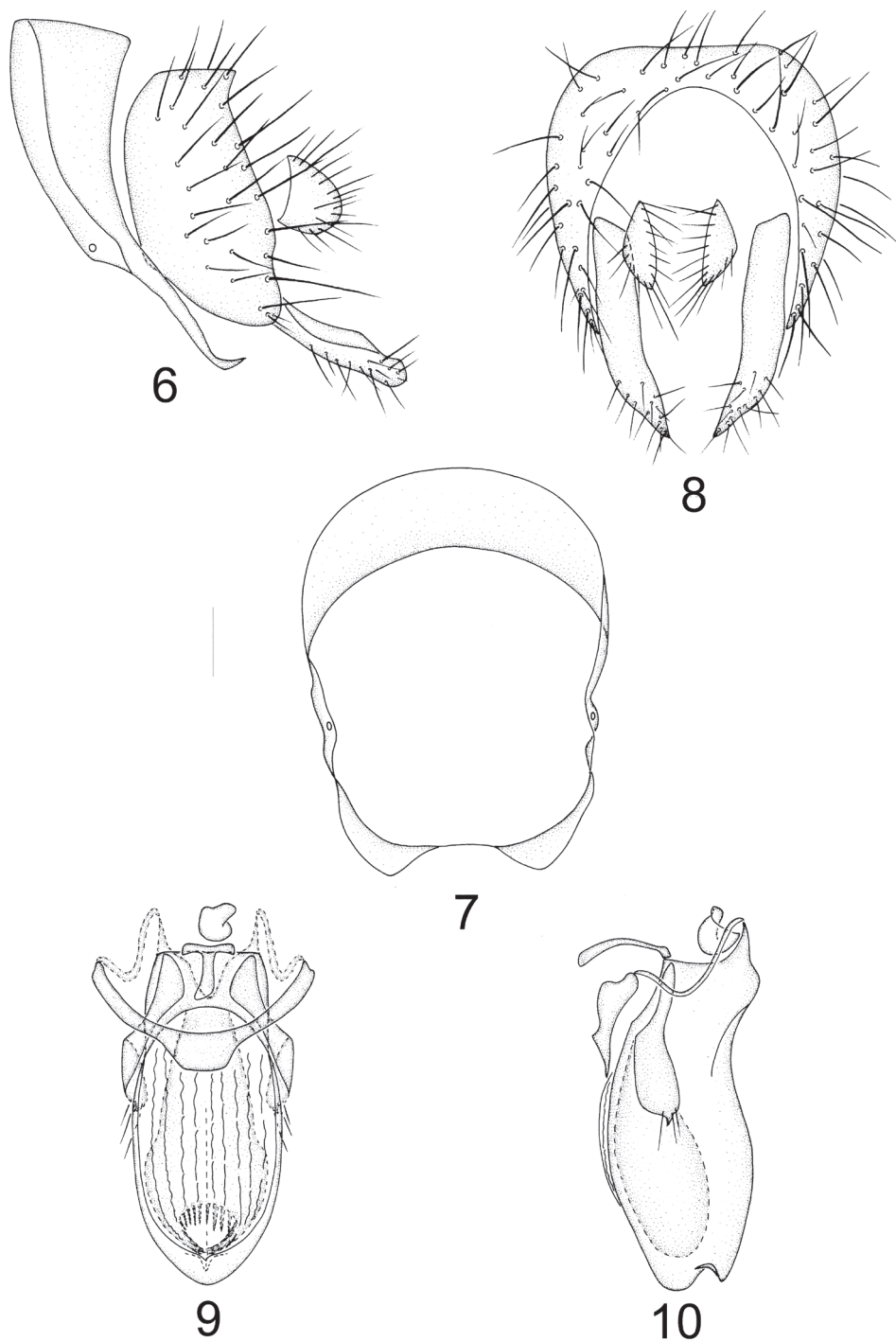
Etymology. The new species is named after the type locality Bawangling National Natural Reserve.

Diagnosis. Arista pubescent, with longest rays about 1/4 height of 1st flagellomere. Mesonotum with 0+2 *dc*, *acr* in 6 rows, two pairs of long *acr*. Mid femur with 3 *a*.

Description. MALE. Body length 4.4 mm, wing length 4.2 mm. FEMALE. Body length 4.0 mm, wing length 3.9 mm.

Head. Frons slightly concaved with yellow anterior margin. Gena about 1/6 eye height. Antenna blackish brown, 1st flagellomere yellow at base, and 1st flagellomere nearly 1.6 times longer than high; arista pubescent, with longest rays about 1/4 height of 1st flagellomere. Proboscis black with dark yellow at apex and palpus black.

Thorax with brownish gray pruinosity. Mesonotum 0+2 *dc* (anterior *dc* far behind transverse scutal suture), *acr* in 6 rows; two pairs of long *acr* present in front of *prsc*, *prsc* slightly shorter than 1st post-sutural *dc*. Legs: tibia black with yellow at base, mid and hind tarsi yellow. Fore femur with 4 *pv* and 8 *pd*, fore tibia with 1 short preapical *ad* and 1 short *apv*. Mid femur with 3 *a* and 1 *app*; mid tibia with 1 strong preapical *ad* and 1 strong *apv*. Hind femura with 1 weak preapical *ad*, hind tibia with 1 weak preapical *ad* and 1 short *apv*. Wing with costa with 2nd (between R_1 and R_{2+3}), 3rd (between R_{2+3} and R_{4+5}) and 4th (between R_{4+5} and M_1) sections in proportion of 7:1.3:1; *r-m* beyond middle of discal cell; ultimate and penultimate



Figures 6–10. *Minettia (Minettiella) bawanglingensis* sp. n. Male. **6** syntergosternite and epandrium, lateral view **7** syntergosternite, anterior view **8** epandrial complex, posterior view **9** aedeagal complex, ventral view **10** aedeagal complex, lateral view. Scale bar = 0.1 mm.

sections of M_1 in proportion of 1:1; ultimate section of CuA_1 about 1/7 of penultimate section.

Abdomen with sparse brownish gray pruinosity. Male genitalia (Figs 6–10): syntergosternite circular with a weak ventral bridge, epandrium with a tiny subapical concave, surstylus separated from epandrium, consisting of a long claviform process with setulae in lateral view and with a long triangular process in posterior view; hypandrium slender, projecting medially and nearly V-shaped; postgonite contorting, consisting of an acute triangular apical process and three apical setae; aedeagus columnar, truncate basally and blunt rounded apically, consisting of a triangular dorsal process subapically in lateral view and a black bottle-shaped inner process with an elliptical incision and many spiculate processes in ventral view; aedeagal apodeme narrow and short, projecting forwards, nearly right angle between hypandrium and aedeagus. Female terminalia (Figs 33–34): sternite 7 trapeziform with long setae on posterior margin, sternite 8 semicircular with three pairs of long setae on posterior margin and sternite 9 with a groove; spermathecae 2+1, round and all stems leading to the three spermathecae narrow apically.

Remarks. The new species is very similar to *M. (Minettiella) dolabriforma* from the Palearctic region in the following characteristics: mesonotum 0+2 *dc*, legs black with base of tibia yellow and mid and hind tarsi yellow, but it can be separated from the latter in the following characteristics: surstylus consisting of a long claviform process with setulae in lateral view and with a long triangular process in posterior view; hypandrium projecting medially and nearly V-shaped; aedeagus consisting of a triangular dorsal process subapically in lateral view and a black, bottle-shaped inner process with an elliptical incision and many speculate processes in ventral view. In *M. (Minettiella) dolabriforma*, the surstylus has a spatulate process, narrow ventrally and pointed at apex in lateral view; the hypandrium is U-shaped; the aedeagus is pointed dorsoapically with a lobate dorsal process in lateral view, and is spinulose and brownish-striated on the median ventral membrane in ventral view (Sasakawa 1995). The new species is also similar to *M. (Minettiella) atrata* from Indonesia (Java) in mesonotum with 0+2 *dc* and a pair of long *acr* present in front of *prsc*, but it can be separated from the latter in the arista having microscopic setulae, and the mid and hind tarsi being yellow. In *M. (Minettiella) atrata*, the arista is short plumose and only the hind tarsi are yellow (Meijere 1910).

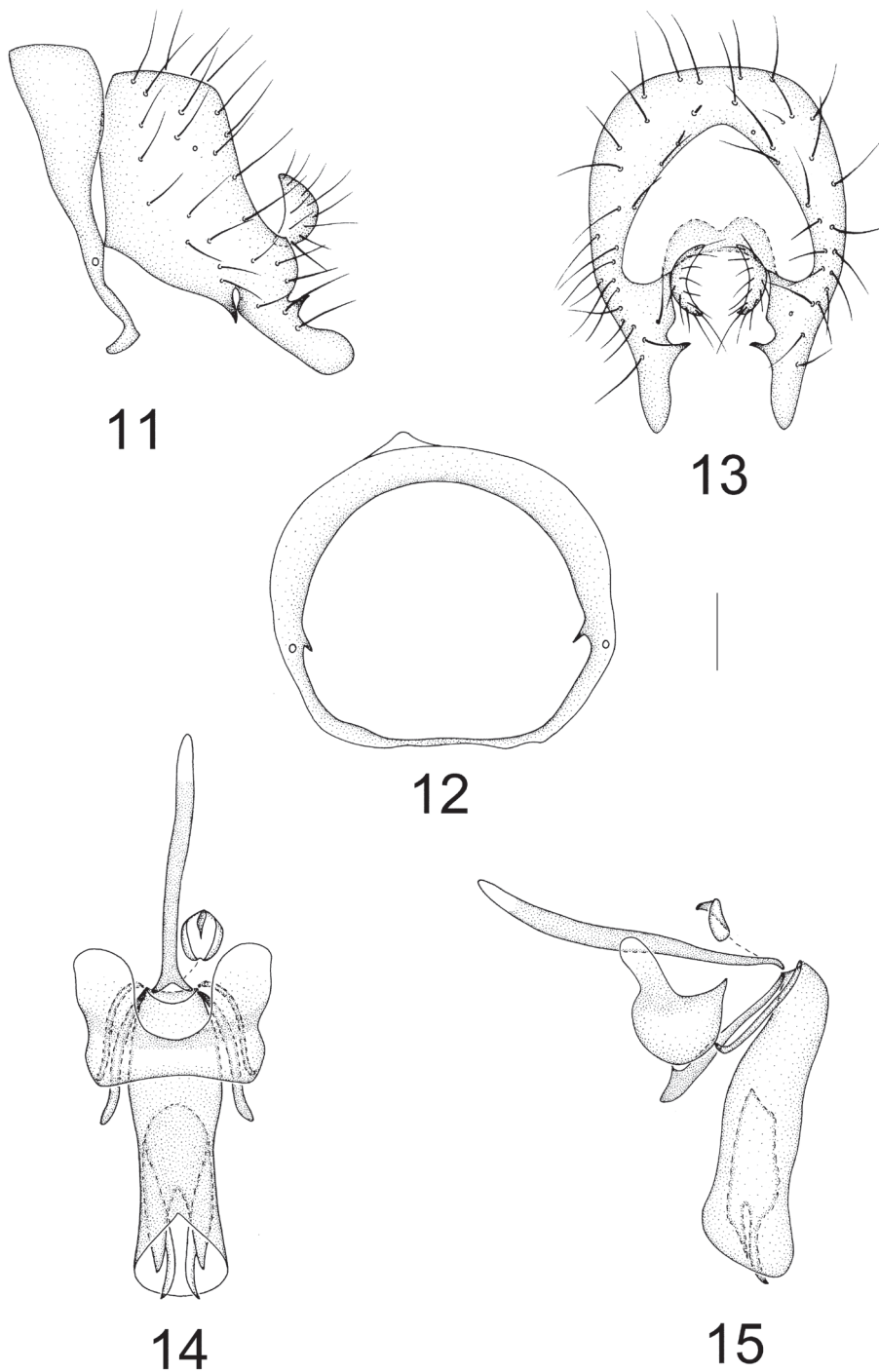
Distribution. China (Hainan).

***Minettia (Minettiella) clavata* sp. n.**

<http://zoobank.org/A727B963-F589-4B19-910C-FC9F3D0BE476>

Figs 11–15, 35–36

Type material. Holotype: ♂ (CAUC), CHINA, Hubei: Shennongjia National Natural Reserve, Pingqian, 1650 m, 26. VII. 2007, Qifei Liu. Paratypes: 4 ♂♂, 1 ♀ (CAUC), CHINA, Hubei: Shennongjia National Natural Reserve, Pingqian, 1650 m, 27. vii.



Figures 11–15. *Minettia (Minettiella) clavata* sp. n. Male. **11** syntergosternite and epandrium, lateral view **12** syntergosternite, anterior view **13** epandrial complex, posterior view **14** aedeagal complex, ventral view **15** aedeagal complex, lateral view. Scale bar = 0.1 mm.

2007, Qifei Liu; 4♀ (CAUC), CHINA, Hubei: Shennongjia National Natural Reserve, Pingqian, 1650 m, 25. vii. 2007, Qifei Liu.

Etymology. Latin, *clavata*, meaning clavate; referring to the club-like surstylus; a feminine adjective.

Diagnosis. Antenna yellow with 1st flagellomere brown on apical 2/3; arista plumose, with longest rays slightly shorter than height of 1st flagellomere. Mesonotum 0+3 *dc*, anterior *dc* weak, hair-like; *acr* in 6 rows. All tibiae black with pale yellow at base; fore tarsi black, mid and hind tarsi dark yellow. Mid femur with 5 *a*.

Description. MALE. Body length 2.9–3.7 mm, wing length 3.2–3.8 mm. FEMALE. Body length 3.0–3.3 mm, wing length 3.3–3.7 mm.

Head. Face slightly shining. Frons with yellow anterior margin. Gena about 1/6 eye height. Antenna yellow with brown on apical 2/3 of 1st flagellomere, 1st flagellomere nearly 1.7 times longer than high; arista plumose, with longest rays slightly shorter than height of 1st flagellomere. A blackish brown rectangular spot present between eye and base of antenna. Proboscis and palpus black.

Thorax with brownish gray pruinosity. Mesonotum 0+3 *dc* (anterior *dc* weak, hair-like, far behind transverse scutal suture), *acr* in 6 rows; *prsc* longer than 1st post-sutural *dc*; anepisternum with setulae on lower margin. Legs: all tibiae black with pale yellow at base; fore tarsi black, mid and hind tarsi dark yellow. Fore femur with 4 *pv* and 6 *pd*, fore tibia with 1 short preapical *ad* and 1 short *apv*. Mid femur with 5 *a* and 1 *app*; mid tibia with 1 strong preapical *ad* and 1 strong *apv*. Hind tibia with 1 weak preapical *ad* and 1 short *apv*. Wing with costa with 2nd (between R_1 and R_{2+3}), 3rd (between R_{2+3} and R_{4+5}) and 4th (between R_{4+5} and M_1) sections in proportion of 4:1.7:1; *r-m* at middle of discal cell; ultimate and penultimate sections of M_1 in proportion of 1:1.1; ultimate section of CuA_1 about 1/5 of penultimate section.

Abdomen shining. Male genitalia (Figs 11–15): syntergosternite circular with an inner tooth near spiracle, epandrium nearly rectangular; surstylus fused with epandrium, clavate with a triangular basal process, a projecting apical process, a small acute ventroapical process and a tiny incision in lateral view; hypandrium nearly U-shaped, hypandrial apodeme distinct; postgonite slender, broad apically in lateral view; aedeagus columnar and rounded apically, with a slight incision; aedeagal apodeme long, slightly shorter than aedeagus. Female terminalia (Figs 35–36): sternite 7 trapeziform, furcating apically with long setae; sternite 8 pale yellow, nearly columnar with a small apical incision; spermathecae 2+1, round.

Remarks. The new species is very similar to *M. (Minettiella) plurifurcata* sp. n. (see discussion under *M. (Minettiella) plurifurcata* sp. n.) from China (Hubei). This new species is also similar to *M. (Minettiella) atrata* from Indonesia (Java) in having the arista short plumose and the mesonotum with *acr* 6 rows, and without other strong *acr* in front of strong *prsc*, but it can be separated from the latter by the mid and hind tarsi being yellow. In *M. (Minettiella) atrata*, only the hind tarsi are yellow (Meijere 1910; Malloch 1929).

Distribution. China (Hubei).

***Minettia (Minettiella) plurifurcata* sp. n.**

<http://zoobank.org/CAF5D321-6C62-41A3-A45F-B3F1FE218BAE>

Figs 16–20

Type material. Holotype: ♂ (CAUC), CHINA, Hubei: Shennongjia National Natural Reserve, Pingqian, 1650 m, 26. vii. 2007, Qifei Liu.

Etymology. Latin, *pluri-*, meaning many, and *furcata*, meaning forked; referring to the aedeagus with forked and acute processes in different lengths; a feminine adjective.

Diagnosis. Arista plumose, with longest rays slightly shorter than height of 1st flagellomere. Thorax with whitish gray pruinosity, sparse on anterior 1/2 and dense on posterior 1/2. Mesonotum 0+3 *dc* (anterior *dc* far behind transverse scutal suture), *acr* in 6 rows. All tibiae pale yellow at base; fore tarsi black, mid and hind tarsi dark yellow. Mid femur with 4 *a*.

Description. MALE. Body length 3.7 mm, wing length 4.2 mm.

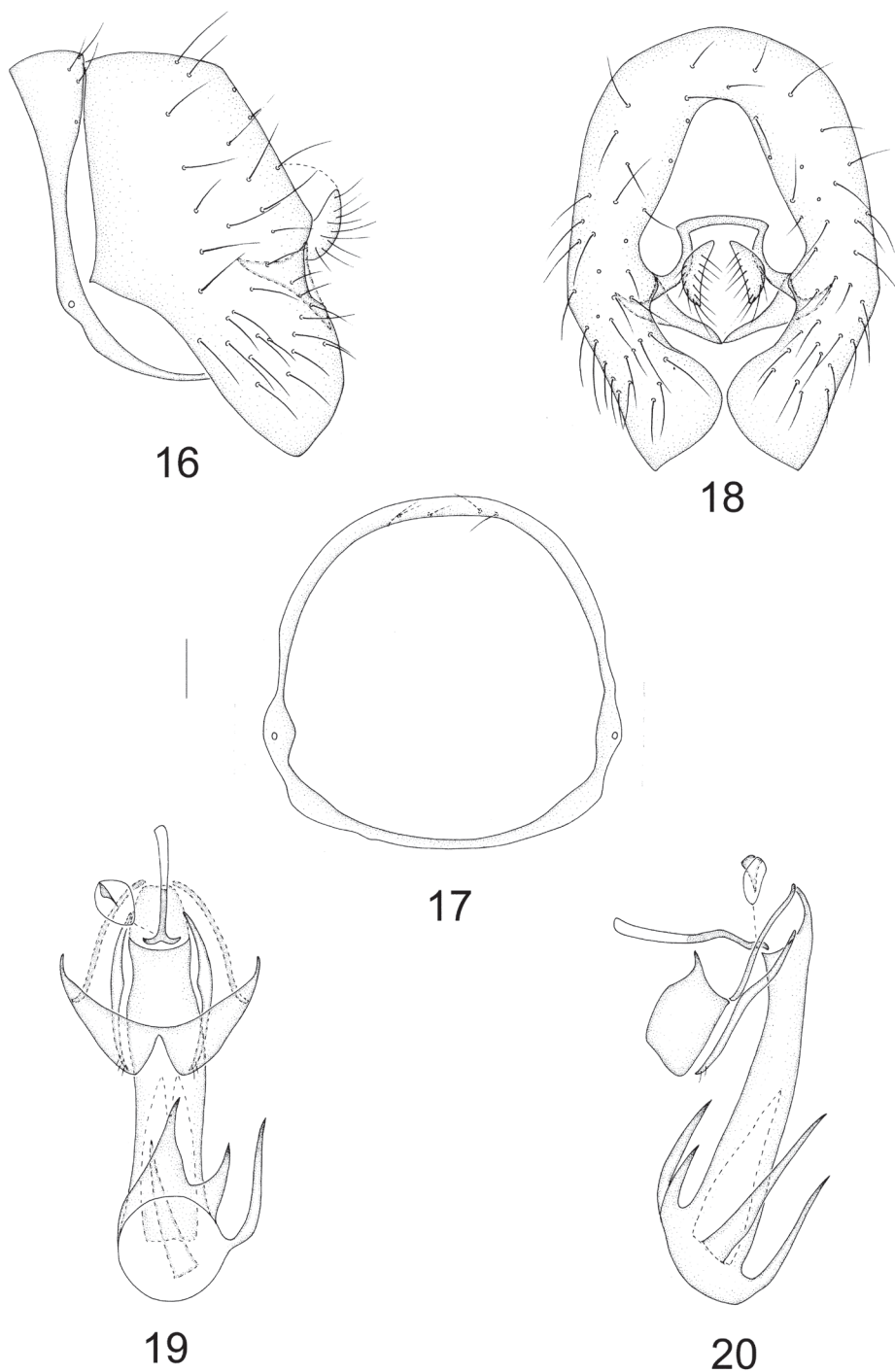
Head. Frons with yellow anterior margin. Gena about 1/7 eye height. Antenna yellow with brown on apical 2/3 of 1st flagellomere, 1st flagellomere nearly 2.0 times longer than high; arista plumose, with longest rays slightly shorter than height of 1st flagellomere. A black round spot present between eye and base of antenna. Proboscis and palpus black.

Thorax with whitish gray pruinosity, sparse on anterior 1/2 and dense on posterior 1/2. Mesonotum 0+3 *dc* (anterior *dc* far behind transverse scutal suture), *acr* in 6 rows; *prsc* as long as 1st postsutural *dc*; anepisternum with setulae on lower margin. Legs: tibia black with pale yellow at base; fore tarsi black, mid and hind tarsi dark yellow. Fore femur with 5 *pv* and 8 *pd*, fore tibia with 1 short preapical *ad* and 1 short *apv*. Mid femur with 4 *a* and 1 *app*; mid tibia with 1 strong preapical *ad* and 1 strong *apv*. Hind tibia with 1 weak preapical *ad* and 1 short *apv*. Wing with costa with 2nd (between R_1 and R_{2+3}), 3rd (between R_{2+3} and R_{4+5}) and 4th (between R_{4+5} and M_1) sections in proportion of 5.2:4:1; *r-m* at middle of discal cell; ultimate and penultimate sections of M_1 in proportion of 1:1.2; ultimate section of CuA_1 about 1/5 of penultimate section.

Abdomen with sparse whitish gray pruinosity. Male genitalia (Figs 16–20): syntergosternite circular with dorsal setulae, epandrium with a wide median incision on dorsal margin in lateral view; surstylus short subuliform and originating from inner side of epandrium in lateral view and convergent apically in posterior view; hypandrium nearly W-shaped; postgonite slender, slightly curved with 2–3 short apical setulae; aedeagus slender, columnar and rounded apically, with furcated acute processes in different length; aedeagal apodeme short, as long as 1/3 length of aedeagus.

FEMALE. Unknown.

Remarks. The new species is very similar to *M. (Minettiella) clavata* sp. n. from China (Hubei) in the following characteristics: *acr* in 6 rows; all femora black and tibiae black with pale yellow at base; fore tarsi black, mid and hind tarsi dark yellow; wing yellow at base, but it can be separated from the latter in the following characteristics: the mesonotum having whitish gray pruinosity, sparse on anterior half and dense on posterior half, and 0+3 *dc*, anterior *dc* strong; the surstylus being long triangular and



Figures 16–20. *Minettia (Minettiella) plurifurcata* sp. n. Male. **16** syntergosternite and epandrium, lateral view **17** syntergosternite, anterior view **18** epandrial complex, posterior view **19** aedeagal complex, ventral view **20** aedeagal complex, lateral view. Scale bar = 0.1 mm.

originating from the inner side of the epandrium. In *M. (Minettiella) clavata*, the mesonotum has 0+3 *dc* with anterior *dc* weak, hair-like; the epandrium is nearly rectangular; the surstylus is fused with the epandrium, and claviform with a triangular basal process a projecting apical process, a small acute ventroapical process and a tiny incision in lateral view.

Distribution. China (Hubei).

Minettia (Minettiella) sasakawai Shi, Wang & Yang, 2011

Sapromyza (Sapromyza) acrostichalis Sasakawa, 2001: 50. Type locality: Vietnam.

Minettia (Minettiella) sasakawai nom. n. (comb. n. preoccupied by *acrostichalis* (Sasakawa & Kozánek, 1995), a new name as a replacement of *acrostichalis* Sasakawa, 2001)

Minettia (Minettiella) sasakawai Shi, Wang & Yang, 2011: 80 (with figures).

Material examined. CHINA, Hainan (CAUC): 5 ♂♂, Ledong, Jianfengling National Natural Reserve, Plant garden, 800 m, 8. v. 2008, Qifei Liu; 1 ♂, Ledong, Jianfengling National Natural Reserve, Sanfenqu, 800 m, 8. v. 2008, Qifei Liu; 2 ♂♂, Ledong, Jianfengling National Natural Reserve, Plant garden, 800 m, 18. v. 2006, Gang Yao; 3 ♂♂, 2 ♀♀, Changjiang, Bawangling National Natural Reserve, Donger station, 1000 m, 24–25. v. 2007, Junhua Zhang; 1 ♂, Baisha, Yinggeling National Natural Reserve, 2. iv. 2006, Hui Dong; 1 ♂, 1 ♀, Baisha, Yinggeling National Natural Reserve, Hongmao village, 430 m, 21–22. v. 2007, Kuiyan Zhang; 1 ♂, Baisha, Yinggeling National Natural Reserve, Hongmao village, 430 m, 21–22. v. 2007, Junhua Zhang; 1 ♀, Baisha, Yinggeling National Natural Reserve, Hongmao village, 430 m, 21. v. 2007, Yongjie Wang.

Diagnosis. Body black with brownish gray. Face and parafacial black flat with dense whitish gray pruinosity. Antennal 1st flagellomere blackish brown except yellow at base. Mesonotum 0+2 *dc* (anterior *dc* far behind transverse scutal suture), *acr* in 4 rows; a pair of long *acr* present in front of *prsc*. Legs mostly black except fore basal tarsus dark yellow on basal 3/4 and mid and hind tarsi dark yellow. Basal part of wing yellow. Abdomen shining black with sparse brownish gray pruinosity.

Redescription. MALE. Body length 3.2–4.1 mm, wing length 3.4–4.4 mm. FEMALE. Body length 3.4–3.7 mm, wing length 3.6–3.9 mm.

Head black. Frons shining black except yellow, slightly concaved anterior margin; *oc* slightly longer than anterior *or*. Gena about 1/6 height of eye. Antenna scape and pedicel yellowish brown, 1st flagellomere blackish brown except yellow on basal part, 1st flagellomere nearly 1.8 times longer than high; arista with microscopic setulae. Proboscis black except yellow at apex; palpus black.

Thorax black with brownish gray pruinosity. Mesonotum with 0+2 *dc* (anterior *dc* far behind transverse scutal suture), *acr* in 4 rows; a pair of long *acr* present in front of *prsc*, *prsc* nearly as long as 1st postsutural *dc*; 1 *ia*, 1 *kepst*. Legs with fore basal tarsus

dark yellow on basal 3/4 and mid and hind tarsi dark yellow. Fore femur with 5 *pv*, 8 *pd*, fore tibia with 1 long preapical *ad* and 1 short *apv*. Mid femur with 4 *a* and 1 *app*; mid tibia with 1 strong preapical *ad*, 1 strong *apv*. Hind femura with 1 weak preapical *ad*, hind tibia with 1 weak preapical *ad* and 1 short *apv*. Wing: costa with 2nd (between R_1 and R_{2+3}), 3rd (between R_{2+3} and R_{4+5}) and 4th (between R_{4+5} and M_1) sections in proportion of 6:1.7:1; *r-m* at middle of discal cell; ultimate and penultimate sections of M_1 in proportion of 1:1.1; ultimate section of CuA_1 about 1/6 of penultimate section.

Abdomen black with sparse brownish gray pruinosity. Male genitalia: protandrium semicircular (with a weak ventral bridge in a few specimens), narrow under spiracle; epandrium slender, with dorsal setae in lateral view; surstylus separated from epandrium, slender, narrow apically with a falcate apical process in lateral view; hypandrium very narrow at middle and broad on two lateral sides; postgonite columnar with two long setae; aedeagus acute apically with a tiny incision in ventral view but oblique truncate apically in lateral view; aedeagal apodeme nearly as long as aedeagus. Female terminalia: tergite 6 with a pair of long dorsal setae on posterior margin; spermathecae 2+1, round.

Distribution. China (Hainan), Vietnam.

Remarks. The species is very similar to *Minettia* (*Minettiella*) *tianmushanensis* sp. n. from Zhejiang (see *M. (Minettiella) tianmushanensis* sp. n.). The new species is also similar to *Minettia* (*Minettiella*) *atrata* from Indonesia (Java) in the following characters: mesonotum with 0+2 *dc* and a pair of long *acr* present in front of *prsc*, but it can be separated from the latter by the arista having microscopic setulae, the mesonotum having the *acr* in 4 rows, and the legs mostly black except the fore basal tarsus dark yellow on basal 3/4 and the mid and hind tarsi dark yellow. In *Minettia* (*Minettiella*) *atrata*, the arista is short plumose, the mesonotum has *acr* in 6 rows and the hind tarsi is yellow (Meijere 1910).

***Minettia* (*Minettiella*) *spinosa* sp. n.**

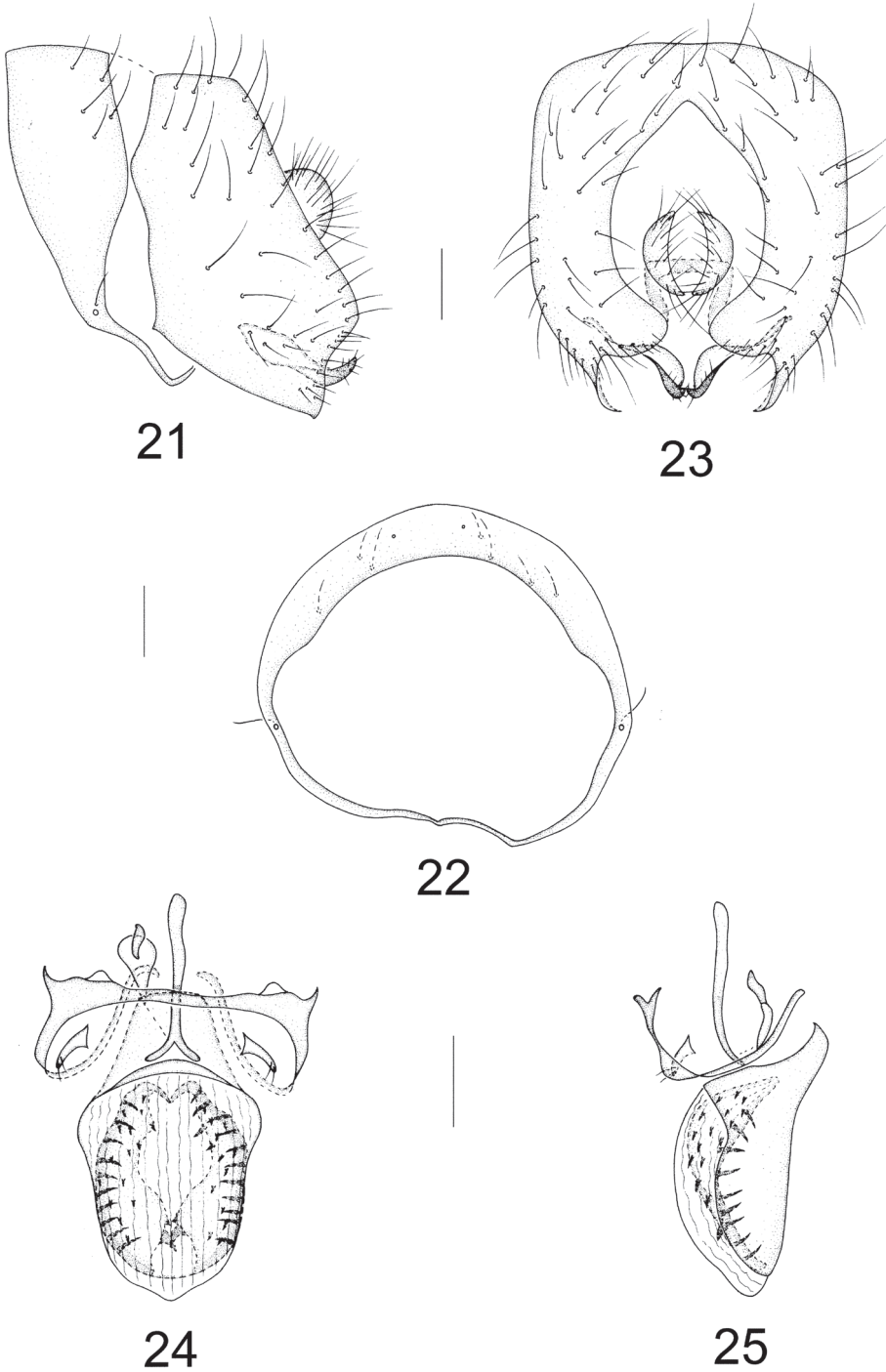
<http://zoobank.org/0AB04092-C12C-4688-9F84-A5B564C66D9C>

Figs 21–25, 39–40

Type material. Holotype ♂ (CAUC), CHINA, Hubei: Shennongjia National Natural Reserve, Pingqian, 1650 m, 25. vii. 2007, Qifei Liu. Paratypes: 4 ♂♂, 6 ♀♀ (CAUC), CHINA, Hubei: as holotype; 6 ♂♂, 5 ♀♀ (CAUC), CHINA, Hubei: Shennongjia National Natural Reserve, Pingqian, 1650 m, 27. vii. 2007, Qifei Liu.

Etymology. Latin, *spinosa*, meaning spinose or with spinules; referring to the aedeagus with many short ventral spinules; a feminine adjective.

Diagnosis. Face with a yellow triangular median spot or only slightly yellow in center of face. Arista with microscopic setulae, longest rays shorter than 1/3 height of 1st flagellomere. All tibiae dark yellow and tarsi dark yellow with tarsomeres 3–5 pale brown (apex of fore tibia pale brown in a few specimens); mid femur with 3 *a*. Wing black at base.



Figures 21–25. *Minettia (Minettiella) spinosa* sp. n. Male. **21** sytergosternite and epandrium, lateral view **22** sytergosternite, anterior view **23** epandrial complex, posterior view **24** aedeagal complex, ventral view **25** aedeagal complex, lateral view. Scale bar = 0.1 mm.

Description. MALE. Body length 3.4–4.0 mm, wing length 3.9–4.4 mm. FEMALE. Body length 3.5–4.1 mm, wing length 4.3–4.6 mm.

Head. Face with a yellow triangular median spot or only slightly yellow in center of face, and parafacial brown with dense whitish gray pruinosity. Frons with yellow anterior margin (sometimes with a wide yellow median stripe in a few of specimens). Gena about $1/6$ eye height. Antenna yellow with pale brown on apical $2/3$ of 1st flagellomere, 1st flagellomere nearly 1.7 times longer than high; arista with microscopic setulae, longest rays shorter than $1/3$ height of 1st flagellomere. An indistinct brown spot present between eye and base of antenna. Proboscis black with dark yellow at apex and palpus black.

Thorax with sparse whitish gray pruinosity. Mesonotum $0+3$ *dc* (anterior *dc* far behind transverse scutal suture), *acr* in 6 rows; *prsc* slightly longer than 1st post-sutural *dc*. Scutellum with dense yellowish brown pruinosity. Legs: all tibiae dark yellow and tarsi dark yellow with tarsomeres 3–5 pale brown (apex of fore tibia pale brown in a few specimens). Fore femur with 5 *pv* and 8 *pd*, fore tibia with 1 short preapical *ad* and 1 short *apv*. Mid femur with 3 *a* and 1 *app*; mid tibia with 1 strong preapical *ad* and 1 strong *apv*. Hind femura with 1 weak preapical *ad*, hind tibia with 1 weak preapical *ad* and 1 short *apv*. Wing slightly yellow with black at base; costa with 2nd (between R_1 and R_{2+3}), 3rd (between R_{2+3} and R_{4+5}) and 4th (between R_{4+5} and M_1) sections in proportion of 11:1.5:1; *r-m* at middle of discal cell; ultimate and penultimate sections of M_1 in proportion of 1:1.2; ultimate section of CuA_1 about $1/6$ of penultimate section.

Abdomen with sparse whitish gray pruinosity. Male genitalia (Figs 21–25): syntergosternite circular with a setula near spiracle, epandrium with a small subapical incision in lateral view and acute apically in posterior view, and surstylus contorting with apical setulae and originating from inner side of epandrium in lateral view; hypandrium slender, nearly H-shaped and hypandrial apodeme indistinct; pregonite tiny, slightly curved with two setulae; aedeagus broad, with dorsal sclerite round apically, membranous parts beyond apex of dorsal sclerite with short spinules and a pair of long hook-like basal processes; aedeagal apodeme slender. Female terminalia (Figs 39–40): sternite 7 rectangular, slightly concave on posterior margin, sternite 8 semicircular with a pair of processes on anterior margin and a wide groove between processes; spermathecae 2+1, round.

Remarks. The new species is similar to *M. (Minettiella) plurifurcata* sp. n. from Hubei in the following characteristics: mesonotum $0+3$ *dc*, *acr* in 6 rows; fore femur with 5 *pv* and 8 *pd*, but it can be separated from the latter in the epandrium having a small subapical incision in lateral view and acute apically in posterior view and the surstylus being contorting with apical setulae in lateral view. In *M. (Minettiella) plurifurcata*, the epandrium has a wide median incision on the dorsal margin in lateral view and the surstylus is short subuliform in lateral view and convergent apically in posterior view.

Distribution. China (Hubei).

***Minettia (Minettiella) tianmushanensis* sp. n.**

<http://zoobank.org/9FE6AC20-3358-4C00-BBEC-98F53FCF9517>

Figs 26–30, 41–43

Type materials. Holotype ♂ (CAUC), CHINA, Zhejiang: Lin'an, Tianmushan National Natural Reserve, 19. vii. 2007, Yajun Zhu. Paratypes: 5♂♂, 3♀♀ (CAUC), Zhejiang: as holotype; 1♂, 1♀ (CAUC), CHINA, Zhejiang: Lin'an, Tianmushan National Natural Reserve, Dajinggu, 20. vii. 2007, Yajun Zhu.

Etymology. The new species is named after the type locality Tianmushan National Nature Reserve, Zhejiang Province

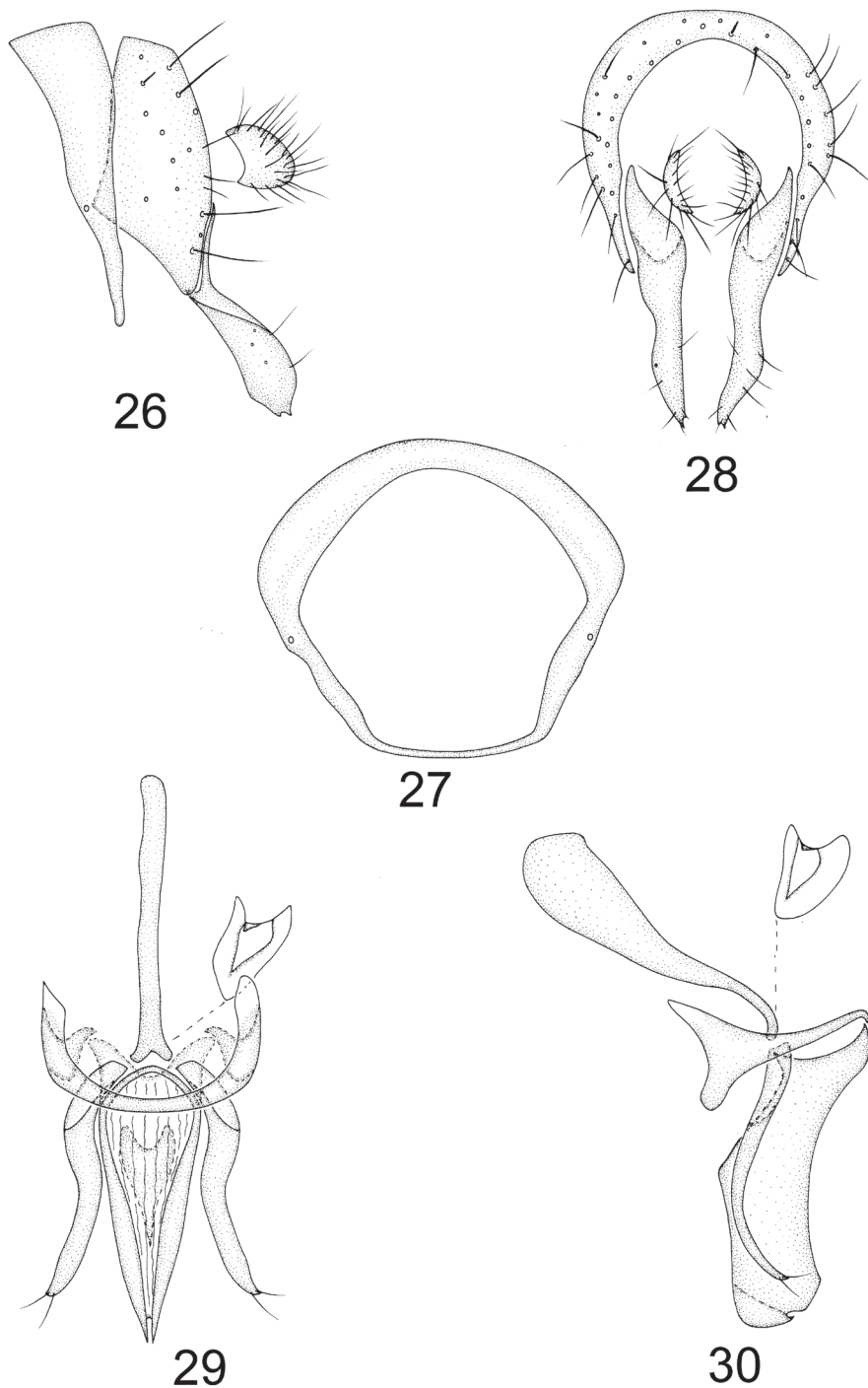
Diagnosis. Frons slightly upturned with yellow anterior margin and short brownish yellow median stripe. Antenna brown with 1st flagellomere yellow at base; arista pubescent, with longest rays about 1/3 height of 1st flagellomere. Mesonotum 0+2 *dc*, *acr* in irregular 4 rows. Mid tarsi dark yellow and basitarsus with 1 subbasal *pv*, and hind tarsi dark yellow.

Description. MALE. Body length 3.4–3.7 mm, wing length 3.4–3.6 mm. FEMALE. Body length 3.2–3.5 mm, wing length 3.3–3.6 mm.

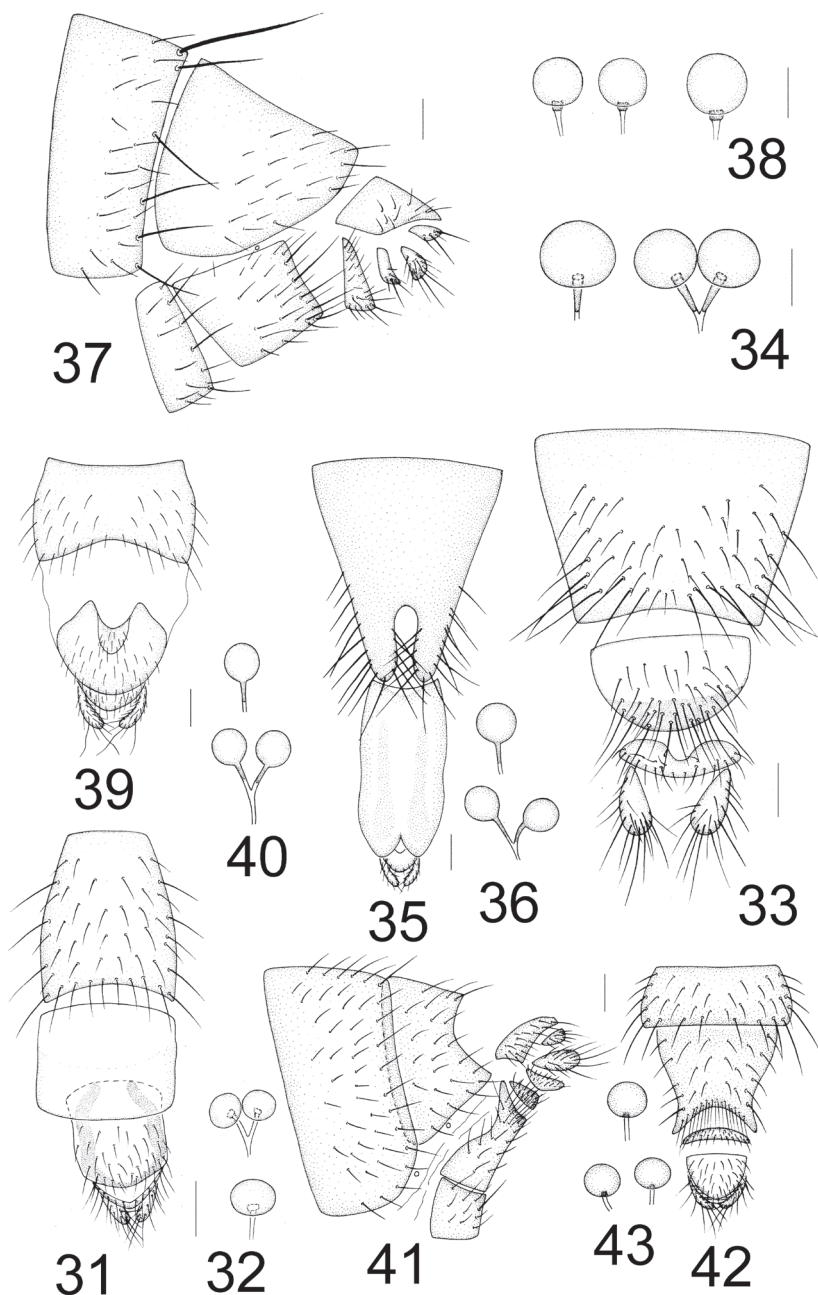
Head. Frons with yellow anterior margin, slightly upturned and short brownish yellow median stripe. Gena about 1/10 eye height. Antenna brown with 1st flagellomere yellow at base and 1st flagellomere nearly 1.8 times longer than high; arista pubescent, longest rays about 1/3 height of 1st flagellomere. Proboscis and palpus blackish brown.

Thorax with brownish gray pruinosity. Mesonotum with 0+2 *dc*, *acr* in irregular 4 rows, a pair of long *acr* in front of *prsc*, *prsc* longer than 1st postsutural *dc*. Legs: tibia black, fore tarsi black, mid and hind tarsi dark yellow. Fore femur with 4–5 *pv* and 8 *pd*, fore tibia with 1 long preapical *ad* and 1 short *apv*. Mid femur with 3–4 *a* and 1 *app*; mid tibia with 1 strong preapical *ad* and 1 strong *apv*, mid basitarsus with 1 subbasal *pv*. Hind femur with 1 preapical *ad*, hind tibia with 1 weak preapical *ad* and 1 short *apv*. Wing with costa with 2nd (between R_1 and R_{2+3}), 3rd (between R_{2+3} and R_{4+5}) and 4th (between R_{4+5} and M_1) sections in proportion of 5:1:1; *r-m* beyond middle of discal cell; ultimate and penultimate sections of M_1 in proportion of 1:1.1; ultimate section of CuA_1 about 1/6 of penultimate section.

Abdomen with sparse brownish gray pruinosity. Male genitalia (Figs 26–30): syntergosternite circular; epandrium slender, nearly rhombic and narrow apically; surstylus separated from epandrium, contorted claviform in lateral view and subuliform in posterior view with two acute apical teeth; hypandrium nearly U-shaped in ventral view, hypandrial apodeme distinct; postgonite S-shaped with two apical setulae in lateral view; aedeagus subuliform, narrow apically with a small incision in ventral view and wide rectangular, slightly projecting subapically with a small acute apical process in lateral view; aedeagal apodeme long, as long as height of aedeagus. Female terminalia (Figs 41–43): ternite 7 concave in lateral view, tergite 8 constricted medially; sternite 9 semicircular, sternite 8 slender, sternite 7 concave apically with a pair of triangular apical processes, curved outward; spermathecae 2+1, elliptical.



Figures 26–30. *Minettia* (*Minettiella*) *tianmushanensis* sp. n. Male. **26** syntergosternite and epandrium, lateral view **27** syntergosternite, anterior view **28** epandrial complex, posterior view **29** aedeagal complex, ventral view **30** aedeagal complex, lateral view. Scale bar = 0.1 mm.



Figures 31–43. Female terminalia. *Minettia* (*Minettiella*) *atrutula* (Meijere, 1924). **31** sternites 7–9, ventral view **32** spermathecae. *Minettia* (*Minettiella*) *bawanglingensis* sp. n. **33** sternites 7–9, ventral view **34** spermathecae. *Minettia* (*Minettiella*) *clavata* sp. n. **35** sternites 7–9, ventral view **36** spermathecae. *Minettia* (*Minettiella*) *sasakawai* Shi, Wang & Yang, 2011. **37** tergites and sternites 6–9, lateral view **38** spermathecae. *Minettia* (*Minettiella*) *spinosa* sp. n. **39** sternites 7–9, ventral view **40** spermathecae. *Minettia* (*Minettiella*) *tianmushanensis* sp. n. **41** tergites and sternites 6–9, lateral view **42** sternites 6–9, ventral view **43** spermathecae. Scale bar = 0.1 mm.

Remarks. The new species is very similar to *M. (Minettiella) sasakawai* from China (Hainan) and Vietnam in the following characteristics: mesonotum with 0+2 *dc*, *acr* in 4 rows, and a pair of long *acr* present in front of *prsc*; wing pale yellow at base, but it can be separated from the latter in the syntergosternite being circular, the surstylus being contorting and claviform in lateral view and subuliform in posterior view with two acute apical teeth, and the female abdominal tergite 6 having no long dorsal setae on the posterior margin. In *M. (Minettiella) sasakawai*, the syntergosternite is semi-circular and narrow under the spiracle; the surstylus is slender, narrow apically with a falcate apical process in lateral view and the female abdominal tergite 6 has a pair of long dorsal setae on the posterior margin.

Distribution. China (Zhejiang).

Key to the subgenera of *Minettia* and the species of the subgenus *Minettiella*

- 1 Frons shining and face flat; arista pubescent; mesonotum with 0–1+2–3 *dc* and 0–1+2–4 long *acr*; katapisternum with 1 strong *kepst*; male genitalia: dorsal aedeagal sclerite present subgenus ***Minettiella* Malloch...6**
- Frons often dull and face slightly concave; arista pubescent or plumose; mesonotum with 0+3 *dc* and 0+2–3 long *acr*; katapisternum with 1 strong and 1 weak *kepst*; male genitalia: dorsal aedeagal sclerite absent (if dorsal aedeagal sclerite present, but no presutural *dc*) **2**
- 2 Lower part of face with a distinct, slight and weakly round swelling on each side **3**
- Lower part of face without round swelling on each side **4**
- 3 Basal part of wing black; arista long plumose, with longest rays longer than height of 1st flagellomere (rarely shorter than height of 1st flagellomere); male genitalia: ventral hypandrial appendages represented by two pairs of sclerites (including some Palearctic and Oriental species) subgenus ***Frendelia* Collin**
- Basal part of wing yellow; arista short plumose, with longest rays as long as 1/2 height of 1st flagellomere; male genitalia: ventral hypandrial appendages represented by one pair of sclerites (such as *M. eoa* Shatalkin, 1992) part of subgenus ***Scotominettia* Shatalkin**
- 4 Male genitalia: ventral hypandrial appendages represented by one pair of sclerites; arista short plumose, with longest rays as long as 1/2 height of 1st flagellomere (such as *Minettia austriaca* Hennig, 1951) part of subgenus ***Scotominettia* Shatalkin**
- Male genitalia: hypandrial appendages without representing by one pair of sclerites, often transverse bar-like, U-shaped or other shapes; arista plumose or pubescent **5**

- 5 Arista with fine microscopic setulae, with longest rays as long as or shorter than 1/4 height of 1st flagellomere (rarely bare); wing yellow at base; male genitalia: aedeagal dorsal sclerite absent; postgonites fused dorsally forming a hood for aedeagussubgenus ***Plesiominettia* Shatalkin**
- Arista short to long plumose with longest rays longer than 1/3 height of 1st flagellomere; wing yellow or brown at base; male genitalia: aedeagal dorsal sclerite present (square, rectangular, triangular and trapeziform); postgonites separatesubgenus ***Minettia* Robineau-Desvoidy**
- 6 Mesonotum with 1+3 *dc*, *acr* in 2 rows, 1+3 long *acr*; male genitalia: epandrium narrow basally and broad apically, with a deep concavity on anterior ventral margin and a digitiform anterior process, triangular apically in lateral view; surstylus elliptical in lateral view (Figs 31–32) ***Minettia* (*Minettiella*) *atratura***
- Mesonotum lacking a presutural *dc*, *acr* in 2–6 rows, without long *acr*; male genitalia: epandrium without deep concavity on anterior ventral margin and a digitiform anterior process in lateral view; surstylus not elliptical in lateral view7
- 7 Mesonotum with 0+2 *dc* **8**
- Mesonotum with 0+3 *dc* (exceptionally *M. (Minettiella) dolabriforma* rarely with 0+3 *dc*, anteriormost *dc* is considerably smaller than usual, only half length of the second *dc*) **12**
- 8 Mesonotum with *acr* in 6 rows (exceptionally *M. (Minettiella) dolabriforma* rarely with *acr* in 6 rows, a pair of *acr* long, just behind level of anterior *dc* and about two third length of *prsc*) **9**
- Mesonotum with *acr* in 4 rows **10**
- 9 *acr* with two pairs of strong setae in front of one pair of *prsc* in dorsal view; arista pubescent, with longest rays about 1/4 height of 1st flagellomere; mid and hind tarsi yellow ***Minettia* (*Minettiella*) *bawanglingensis* sp. n.**
- *acr* with a pair of strong setae in front of one pair of *prsc* in dorsal view; arista plumose; only hind tarsi yellow ***Minettia* (*Minettiella*) *atrata***
- 10 Arista with microscopic setulae; male genitalia: surstylus narrow apically with a falcate apical process in lateral view ***Minettia* (*Minettiella*) *sasakawai***
- Arista pubescent, with longest rays about 1/3 height of 1st flagellomere; male genitalia: surstylus wide apically with teeth or acute process in lateral view **11**
- 11 Female sternite 9 rectangular, about three times as wide as long, and sternite 7 without triangular apical processes; male genitalia: surstylus with an acute process projecting forwards in lateral view ***Minettia* (*Minettiella*) *dolabriforma***
- Female sternite 9 semicircular, sternite 7 with a pair of triangular apical processes (Figs 41, 42); male genitalia: surstylus contorted claviform in lateral view and subuliform in posterior view, with two acute apical teeth (Figs 26, 28) ***Minettia* (*Minettiella*) *tianmushanensis* sp. n.**

- 12 Mesonotum with *acr* in 2 rows 13
- Mesonotum with *acr* in 6 rows 14
- 13 Anepisternum with bluish grey pruinosity; mid and hind tibiae yellow.....
.....*Minettia* (*Minettiella*) *acrostichalis*
- Anepisternum with whitish grey pruinosity; mid and hind tibiae yellow
except blackish apical 1/4.....*Minettia* (*Minettiella*) *coracina*
- 14 Mesonotum with brownish grey pruinosity, 1st postsutural *dc* weak, hair-
like, *prsc* longer than 1st postsutural *dc*; male genitalia: surstylus fused with
the epandrium, claviform with a triangular basal process, a projecting apical
process, a small acute ventroapical process and a tiny incision in lateral view
(Figs 11, 13) *Minettia* (*Minettiella*) *clavata* sp. n.
- Mesonotum with whitish grey pruinosity, 1st postsutural *dc* strong, *prsc* as
long as or longer than 1st postsutural *dc*; male genitalia: surstylus articulated
with epandrium, triangular or lobe-like with a single process 15
- 15 Face and parafacial with sparse whitish gray pruinosity; arista short plumose,
longest rays slightly shorter than height of 1st flagellomere; mid femur with
4 *a*; male genitalia: epandrium with a wide median incision on dorsal margin
in lateral view; surstylus short subuliform and originating from inner side of
epandrium in lateral view and converging apically in posterior view (Figs 16,
18); female unknown.....*Minettia* (*Minettiella*) *plurifurcata* sp. n.
- Face with a yellow triangular median spot or only slightly yellow at middle
of face, and parafacial with dense whitish gray pruinosity; arista with micro-
scopic setulae, longest rays shorter than 1/3 height of 1st flagellomere; mid
femur with 3 *a*; male genitalia: epandrium with a small subapical incision in
lateral view and acute apically in posterior view, surstylus contorted with api-
cal setulae and originating from inner side of epandrium in lateral view (Figs
21, 23); female sternite 8 semicircular with a pair of processes on anterior
margin and a wide groove between processes (Fig 39)
.....*Minettia* (*Minettiella*) *spinosa* sp. n.

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Appendix

Genus *Minettia* Robineau-Desvoidy, 1830

Subgenus *Minettiella* Malloch, 1929

1. *Minettia* (*Minettiella*) *acrostichalis* (Sasakawa & Kozánek, 1995) (*Calliopum*). Oriental: North Korea.
2. *Minettia* (*Minettiella*) *atrata* (Meijere, 1910) (*Lauxania*). Oriental: Indonesia, Malaysia.
3. *Minettia* (*Minettiella*) *atratura* (Meijere, 1924) (*Lauxania*). Oriental: China (Taiwan, Hainan), Indonesia, Vietnam.
4. *Minettia* (*Minettiella*) *bawanglingensis* sp. n. Oriental: China (Hainan).
5. *Minettia* (*Minettiella*) *clavata* sp. n. Oriental: China (Hubei).
6. *Minettia* (*Minettiella*) *coracina* Shatalkin, 1993. Palearctic: Russia.
7. *Minettia* (*Minettiella*) *dolabriforma* (Sasakawa & Kozánek, 1995) (*Calliopum*). Palearctic: North Korea, Japan, Russia.
Minettia japonica Sasakawa, in Sasakawa & Mitsui, 1995. Syn. n.
Minettiella elbergi Shatalkin, 1996. Syn. n.
8. *Minettia* (*Minettiella*) *plurifurcata* sp. n. Oriental: China (Hubei).
9. *Minettia* (*Minettiella*) *spinosa* sp. n. Oriental: China (Hubei).
10. *Minettia* (*Minettiella*) *sasakawai* Shi, Wang & Yang, 2011. Oriental: China (Hainan), Vietnam.
Sapromyza acrostichalis Sasakawa, 2001. [Homonym of *Calliopum acrostichalis* Sasakawa & Kozánek, 1995, when in *Minettia*]
11. *Minettia* (*Minettiella*) *tianmushanensis* sp. n. Oriental: China (Zhejiang).

Amphibians of Serra Bonita, southern Bahia: a new hotspot within Brazil's Atlantic Forest hotspot

Iuri Ribeiro Dias^{1,2}, Tadeu Teixeira Medeiros³,
Marcos Ferreira Vila Nova¹, Mirco Solé^{1,2}

1 Departamento de Ciências Biológicas, Universidade Estadual de Santa Cruz, Rodovia Jorge Amado, km, 16, 45662-900 Ilhéus, Bahia, Brasil **2** Graduate Program in Applied Zoology, Universidade Estadual de Santa Cruz, Rodovia Jorge Amado, km 16, 45662-900 Ilhéus, Bahia, Brasil **3** Conselho de Curadores das Coleções Científicas, Universidade Estadual de Santa Cruz, Rodovia Jorge Amado, km 16, 45662-900 Ilhéus, Bahia, Brasil

Corresponding author: Iuri Ribeiro Dias (iurirdias@hotmail.com)

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Abstract

We studied the amphibian community of the Private Reserve of Natural Heritage (RPPN) Serra Bonita, an area of 20 km² with steep altitudinal gradients (200–950 m a.s.l.) located in the municipalities of Camacan and Pau-Brasil, southern Bahia State, Brazil. Data were obtained at 38 sampling sites (including ponds and transects within the forest and in streams), through active and visual and acoustic searches, pitfall traps, and opportunistic encounters. We recorded 80 amphibian species distributed in 15 families: Aromobatidae (1), Brachycephalidae (3), Bufonidae (4), Centrolenidae (2), Ceratophryidae (1), Craugastoridae (7), Eleutherodactylidae (2), Hemiphractidae (2), Hylidae (42), Hylodidae (1), Leptodactylidae (7), Microhylidae (3), Siphonopidae (1), Odontophrynidae (3) and Pipidae (1). Species richness was positively correlated with monthly rainfall. Near 36% of the species were found in strictly forest environments, 15% are endemic to Bahia State and 77.2% are endemic to the Atlantic Forest biome. The large species diversity of this small area, the high degree of endemism and the taxonomic and biogeographic significance turn the Serra Bonita mountain into a hotspot for amphibians within Brazil's Atlantic Forest hotspot.

Resumo

Neste trabalho, estudamos a comunidade de anfíbios da Reserva Particular do Patrimônio Natural (RPPN) Serra Bonita que possui área de 20 km² com gradientes altitudinais abruptos (200–950 m acima do nível do mar), localizada nos municípios de Camacan e Pau Brasil, sul do Estado da Bahia, Brasil. Os dados foram obtidos em 38 diferentes sítios amostrais (incluindo poças, transectos no interior da floresta e em riachos)

através de procura ativa visual e acústica, armadilhas de interceptação e queda e por encontros oportunistas. Foram registradas 80 espécies de anfíbios distribuídas em 15 famílias: Aromobatidae (1), Brachycephalidae (3), Bufonidae (4), Centrolenidae (2), Ceratophryidae (1), Craugastoridae (7), Eleutherodactylidae (2), Hemiphractidae (2), Hylidae (42), Hylodidae (1), Leptodactylidae (7), Microhylidae (3), Siphonopidae (1), Odontophrynidae (3) e Pipidae (1). A riqueza foi positivamente correlacionada com a precipitação mensal. Aproximadamente 36% das espécies foram encontradas em ambientes estritamente florestais, 15% são endêmicas do Estado da Bahia e 77.2% são endêmicas do bioma Mata Atlântica. A alta diversidade de espécies desta pequena área, o elevado endemismo e a relevância taxonômica e biogeográfica tornam a Serra Bonita um ‘hotpoint’ para anfíbios no ‘hotspot’ da Mata Atlântica.

Keywords

Anura, Mountain, Biodiversity, species distribution, species richness

Introduction

Among vertebrates, amphibians are considered the most threatened group on the planet (Hoffmann et al. 2010). Near a third of the world’s amphibian species are endangered (Stuart et al. 2004). The main threats to the group are loss and fragmentation of habitat (Young et al. 2004, Becker et al. 2007, Loyola et al. 2007), climate change (Pounds et al. 2006, Blaustein and Johnson 2003), introduction of exotic species (Kats and Ferrer 2003) and diseases (Lips et al. 2003).

Despite Brazil showing the highest worldwide diversity of amphibians (Segalla et al. 2012), it does not rank within the first positions in the number of endangered species. This is probably due to the lack of data regarding most Brazilian species, once the country is also the world leader in species classified as Data Deficient (DD) – near 25% of the assessed species (IUCN 2008). Many of this species could be facing extinction but are not in the scope of conservation actions, since we cannot determine the major threats to their populations due to the absence of adequate sampling along the Brazilian territory (Trindade-Filho et al. 2012, Verdade et al. 2012, Campos et al. 2013, Morais et al. 2013).

Brazil’s Atlantic Forest is one of the five most important global hotspots of biodiversity (Myers et al. 2000). It harbors more than half of the country’s amphibians (Haddad et al. 2013) and exhibits high endemism rates (> 85% of species) for this taxonomic group (Cruz and Feio 2007). Such high biodiversity is faced with the current situation of the biome, with fewer than 11.7% of its original area remaining and only 1% of its total area being legally protected (Ribeiro et al. 2009). In addition, the number of amphibian species is expected to decline within the Atlantic Forest network of protected areas due to climate change, according to projections made by Lemes et al. (2014).

Given the devastation of the Atlantic Forest biome, where more than half of the Brazilian amphibians live, coupled with the lack of information to assess the conservation status of many species, primary studies are urgently needed to overcome these shortfalls.

The central region of the Atlantic Forest – including the south of Bahia – was deemed as a zone of climatic stability during the Quaternary glaciations and was the

greatest refuge for amphibians in the Atlantic Forest during that period (Carnaval et al. 2009). This region is regarded as an important center of diversification and endemism for plants (Thomas et al. 1998) and different groups of animals (Haffer 1974, Brown 1991, Bencke et al. 2006).

In a comparison of the diversity of trees from different tropical forests in the world, a forest remnant of southern Bahia was amongst those with the greatest richness and was thereby considered a hotspot within the Atlantic Forest hotspot (Martini et al. 2007). The identification of areas with large numbers of endemic species and species diversity within the major global hotspots assists in planning conservation actions aimed at smaller areas that can be more easily managed and protected than larger ones (Murray-Smith et al. 2008).

The study of the species richness and species composition in a given area is essential to know the functional structure of biological communities, as well as to understand the dynamics between fragments, serving as an instrument that contributes in decisions relative to species conservation (Droege et al. 1998, Haddad 1998). As highlighted by Verdade et al. (2012), further investments in basic research – in particular regarding the collection of field data during inventories of fauna and taxonomic reviews – are necessary to better understand the extraordinary biodiversity of Brazilian amphibians as to properly assess their conservation status and help design conservation strategies for this taxonomic group.

There is a huge lack of information about the occurrence of amphibians in the State of Bahia, Brazil. This can be noticed by the frequent publication of notes regarding the increased distribution of species in the state (e.g. Orrico 2010, Dias et al. 2010, Camurugi et al. 2010, Dias et al. 2011) and the large number of new species described over the last years (e.g. Napoli et al. 2011a, Lourenço-de-Moraes et al. 2012, Teixeira-Jr et al. 2013, Caramaschi et al. 2013). Furthermore, only eleven scientific articles contain lists of amphibian species in the state (Silvano and Pimenta 2003, Juncá 2005, Juncá 2006, Bastazini et al. 2007, Protázio et al. 2009, Valdujo et al. 2009, Camurugi et al. 2010, Xavier and Napoli 2011, Valdujo et al. 2011, Garda et al. 2013, Lantyer-Silva et al. 2013). Most of the available information regarding amphibians of southern Bahia are results of the work of Silvano and Pimenta (2003). Despite the fact that a small sampling effort was applied (about four nights at each fragment), a considerable number of fragments were sampled in 19 localities and a total of 92 species were found.

Due to difficult access or the lack of suitability for agricultural purposes, most forest remnants that exist outside protected areas in southern Bahia are situated on slopes or mountain tops (Thomas et al. 1998, 2008). From the scientific point of view, though, these places are still little explored even considering areas of utmost biological importance (Martinelli 2007). As for the montane areas, the few existing data exhibit a high diversity of species (Amorim et al. 2005, 2009, Matos et al. 2010, Rocha and Amorim 2012), many of which endemic and new to science (e.g. Amorim and Leme 2009, Napoli et al. 2011a, Machado et al. 2013, Teixeira-Jr et al. 2013).

Accordingly, the objective of this study was to inventory the amphibians of the Private Reserve of Natural Heritage (RPPN) Serra Bonita, a montane area covered by

Tropical Rainforest in southern Bahia State, Brazil. Our data reveal that Serra Bonita is one of the amphibian habitats with the greatest diversity in the world, a hotspot within the Atlantic Forest hotspot for this taxonomic group.

Materials and methods

Study area

The Serra Bonita Reserve (Figure 1) is located in the municipalities of Camacan and Pau-Brasil, Bahia State, Brazil (15°23'S, 39°33'W). The region is known as the “South Coast” and is located about 130 km from the city of Ilhéus and 526 km from the state capital – Salvador. Under a free lease agreement, the Uiraçu Institute administers around 20 km² from which 12 were transformed into a Private Reserve of Natural Heritage (PRNP or RPPN) located within the Central Corridor of the Atlantic Forest (Instituto Uiraçu 2009).

The area comprises steep altitudinal gradients (200–950 m a.s.l.) that cause changes in humidity and temperature along the gradient. The vegetation consists of a mosaic of forest fragments in different stages of ecological succession, with some *cabruças* (cacao plantations where native woody plants are used for shading) and pastures. Preliminary floristic studies have identified 628 angiosperm species divided into 103 families (Amorim et al. 2009), and 173 species of ferns, as well as nine lycophytes; 44 of all species were new records for the State of Bahia and northeastern Brazil (Matos et al. 2010).

The climate in the region is the Af type of Köppen (1936) and is characterized as hot and humid without a dry season. During the study period, the average monthly rainfall was 160.9 mm (23.2–270.8 mm), while the average minimum air temperature was 17.2 °C (13.5–20.1 °C) and the maximum 25.8 °C (21.9–29.4 °C). Summarized data is displayed in Figure 2. These data were collected using two rain gauges installed at the site, one in the lower area (200 m a.s.l.) and another in the higher area (850 m a.s.l.), plus eight minimum and maximum thermometers placed along the forest, four in the low area and four situated upland.

Collection and analysis of data

We conducted monthly field trips over six consecutive days from December 2009 to November 2010 and also recorded species during four other trips that lasted four days each, in July and December 2008, and February and May 2009, totaling 88 field days.

The inventory of amphibians was carried out using the following methods: (1) active visual and acoustic search (Heyer et al. 1994) via transects installed in the inner forest and streams; (2) pitfall traps (Cechin and Martins 2000); (3) active search in permanent and temporary ponds (Heyer et al. 1994); (4) opportunistic records done while the team moved along the trails, including specimens found by others.

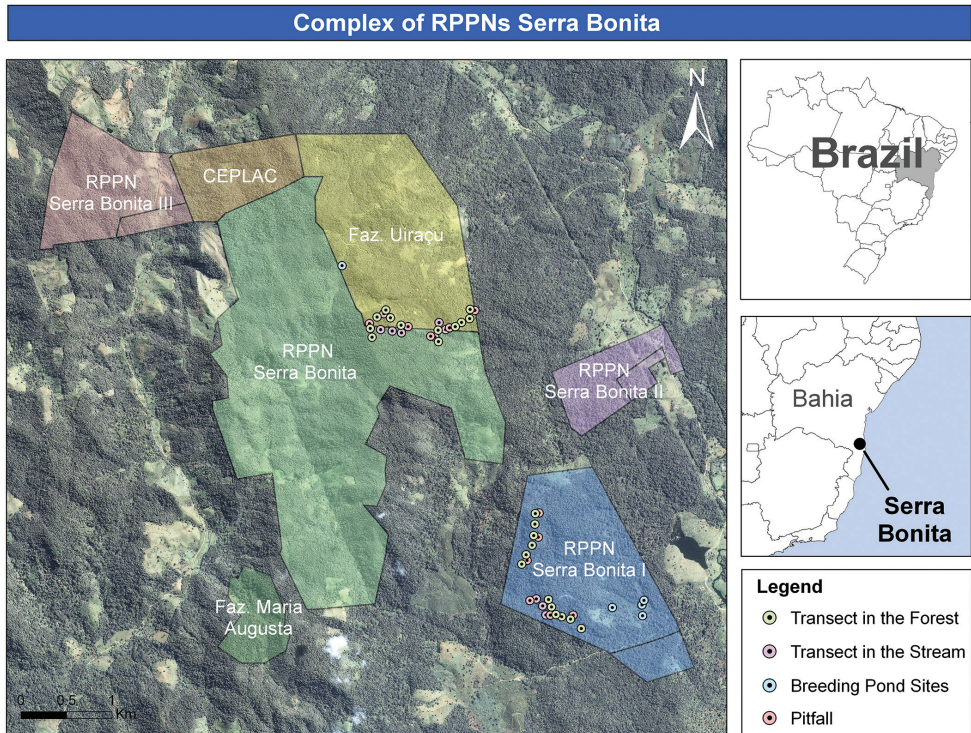


Figure 1. Map and sampling sites in the RPPN Serra Bonita, Bahia State, Northeastern Brazil.

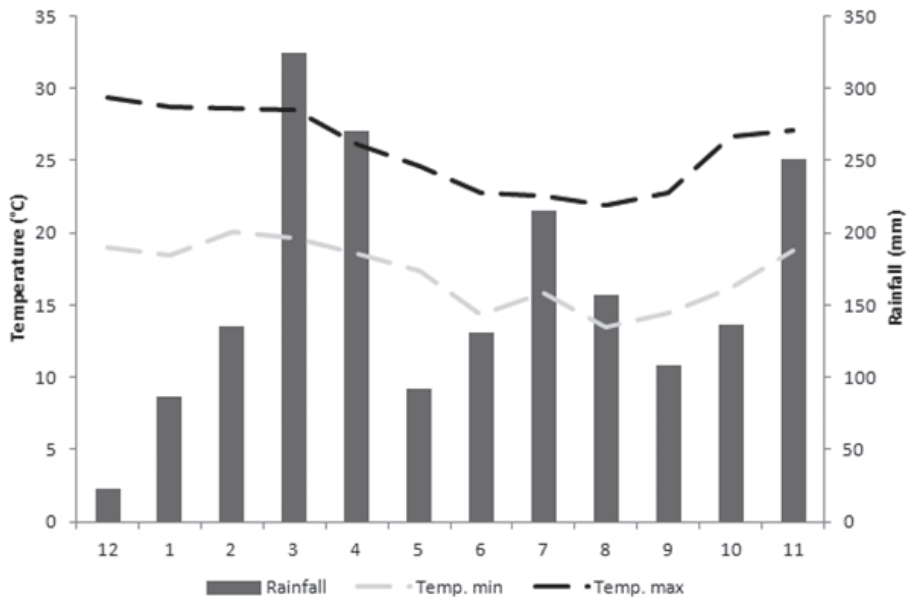


Figure 2. Rainfall data and minimum and maximum temperatures at the RPPN Serra Bonita between December 2009 and November 2010.

From December 2009 to November 2010 we sampled 24 100-m transects placed in the inner forest and nine 50-m transects placed in streams. Active search was more frequently conducted by two researchers and occasionally by three. All transects were once inspected in every sampling month. Transects placed in the inner forest were traversed for 40 minutes, on average, totaling 192 hours/man. The transects placed in the streams, in turn, were traversed for 30 minutes, on average, totaling 54 hours/man.

We installed 12 pitfall traps, which were formed by four 100-L buckets shaped as “Y” and fitted with a one-meter-high canvas drift fence that connected them with five meter in length; the buckets remained open three nights per month over the year, totaling a sampling effort of 1728 buckets/day.

Five pools were occasionally sampled: two in the *cabruca*, another two in the pastures and another at the edge of the forest, with an overall sampling effort of about 25 hours. Temporary ponds formed on the used roads after heavy rain were also sampled.

The species that were found during reproductive activity were classified as having short (1–2 months), medium (3–7 months) and long (8–12 months) mating seasons. We considered the presence of males vocalizing as indicative of reproductive activity for species.

In order to verify a possible correlation between the monthly observed species richness and abiotic factors (rainfall, maximum and minimum temperatures), we used the Pearson’s correlation coefficient. Normality was checked with the Shapiro-Wilk test. Correlations were computed using the SPSS 13.0 software. To calculate the number of species that could occur within the RPPN Serra Bonita, we used the shapes relative to the area of occurrence of amphibians provided by IUCN (2008) overlapped with the limits of the two municipalities in which the PRNP is located (Pau Brasil and Camacan), using the ArcGIS program.

All animals were collected under license provided by IBAMA and/or the Chico Mendes Institute for Biodiversity Conservation upon permission of the directors of local reserves. Vouchers were deposited at the Museu da Universidade Estadual de Santa Cruz (MZUESC), Ilhéus, Bahia, Brazil (Appendix I).

Results

Eighty amphibian species were found in the RPPN Serra Bonita: a single species of Gymnophiona (*Siphonops annulatus* – Siphonopidae) and 79 species of anurans, allocated into 14 families (Table 1; Figures 3–6). The species richness observed in the Serra Bonita mountain is the second highest recorded for the Atlantic Forest biome and almost doubles those found in other locations in the State of Bahia (Table 2). It is noteworthy that only the Ecological Reserve of Michelin had a similar sampling effort as the one applied to our study in the state of Bahia.

Among the species found in the study area that were already classified by the IUCN ($n = 63$), the vast majority ($n = 48$; 76.1%) are considered as “Least Concern” and 20.6% ($n = 13$) as data deficient to assess their conservation status

Table 1. Amphibian species found in the RPPN Serra Bonita, southern Bahia, Brazil. Caption. IUCN (International Union for Conservation of Nature and Natural Resources): DD = Deficient Data; LC = Least Concern; VU = Vulnerable; NT = Near Threatened. Habitat: LL = Leaf litter or understory; S = Streams; P = ponds; B = bromeliads or epiphytes; Mating Activity = Period of mating activity: S = short (1–2 months); M = medium (3–7 months); and L = long (8–12 months); Sampling Method: OE = Opportunistic encounters; TF = Transect in the forest; TS = Transect in the streams; P = Pitfall; BP = Breeding pond sites. * = species only found in the inner forests; † = only acoustic record; # only recorded once or twice during the sampling.

Family/Species	IUCN	Habitat	Mating Activity	Sampling Method
AROMOBATIDAE				
<i>Allobates olfersioides</i> (Lutz, 1925)*	VU	LL e S	-	P, OE
BRACHYCEPHALIDAE				
<i>Brachycephalus pulex</i> Napoli, Caramaschi, Cruz & Dias, 2011*	-	LL	-	TF
<i>Ischnocnema verrucosa</i> Reinhardt & Lütken, 1862*	DD	S, LL	S	TS, TF, P
<i>Ischnocnema</i> sp. (gr. <i>parva</i>)*	-	LL	S	TS, TF, P, OE
BUFONIDAE				
<i>Rhinella crucifer</i> (Wied-Neuwied, 1821)	LC	P, LL	M	TF, TS, P, OE, BP
<i>Rhinella granulosa</i> (Spix, 1824)	LC	P, LL	S	OE, BP
<i>Rhinella hoogmoedi</i> Caramaschi & Pombal, 2006	LC	P, S	S	TF, TS, P, OE
<i>Rhinella jimi</i> (Stevaux, 2002)	LC	LL	-	OE
CENTROLENIDAE				
<i>Vitreorana eurygnatha</i> (A. Lutz, 1925)*	LC	S	L	TS
<i>Vitreorana uranoscopa</i> (Müller, 1924)*	LC	S	S	TS
CERATOPHRYIDAE				
<i>Ceratophrys aurita</i> (Raddi, 1823) #	LC	LL	-	OE
CRAUGASTORIDAE				
<i>Haddadus binotatus</i> (Spix, 1824)	LC	LL	L	TF, TS, P, OE
<i>"Eleutherodactylus" bilineatus</i> (Bokermann, 1975)*	LC	LL	S	TF, P, OE
<i>Pristimantis paulodutrai</i> (Bokermann, 1975)	LC	LL	-	OE
<i>Pristimantis</i> sp. 1*	-	B	L	TF, TS, OE
<i>Pristimantis</i> sp. 2*	-	LL	L	TF, TS, OE
<i>Pristimantis</i> sp. 3* #	-	LL	S	OE
<i>Pristimantis vinhai</i> (Bokermann, 1975)	LC	LL	L	TF, TS, OE
ELEUTHERODACTYLIDAE				
<i>Adelophryne mucronatus</i> Lourenço-de-Moraes, Solé & Toledo, 2012*	-	LL	-	TF, TS, OE
<i>Adelophryne</i> sp.*	-	LL	-	TF, TS, OE
HEMIPHRACTIDAE				
<i>Gastrotheca</i> sp.* #	-	B	-	TF, OE
<i>Gastrotheca pulchra</i> Caramaschi & Rodrigues, 2007*	DD	B	-	TF, TS
HYLIDAE				
<i>Aplastodiscus</i> cf. <i>weygoldti</i> (Cruz & Peixoto, 1985)*	NT	S	L	TF, TS, OE
<i>Aplastodiscus ibirapitanga</i> (Cruz, Pimenta & Silvano, 2003)*	LC	S	M	TF, TS, OE, BP
<i>Bokermannohyla circumdata</i> (Cope, 1871)*	LC	S	M	TF, TS, OE
<i>Bokermannohyla lucianae</i> (Napoli & Pimenta, 2003)*	DD	S	L	TF, TS, OE
<i>Dendropsophus anceps</i> (Lutz, 1929)	LC	P	M	TF, BP, OE
<i>Dendropsophus bipunctatus</i> (Spix, 1824) #	LC	P	S	BP
<i>Dendropsophus branneri</i> (Cochran, 1948)	LC	P	L	BP

Family/Species	IUCN	Habitat	Mating Activity	Sampling Method
<i>Dendropsophus elegans</i> (Wied-Neuwied, 1824)	LC	P	L	BP, TS
<i>Dendropsophus giesleri</i> (Mertens, 1950)	LC	P	M	BP
<i>Dendropsophus haddadi</i> (Bastos & Pombal, 1996)	LC	P	L	TS, BP
<i>Dendropsophus novaisi</i> (Bokermann, 1968) #	DD	P	S	BP, TF
<i>Dendropsophus minutus</i> (Peters, 1872)	LC	P	S	BP
<i>Dendropsophus</i> aff. <i>oliveirai</i> (Bokermann, 1963)	LC	P	L	BP
<i>Hypsiboas albomarginatus</i> (Spix, 1824)	LC	P	L	BP
<i>Hypsiboas atlanticus</i> (Caramaschi & Velosa, 1996) †	LC	P	M	BP, OE
<i>Hypsiboas crepitans</i> (Wied-Neuwied, 1824)	LC	P	M	TF, BP
<i>Hypsiboas exastis</i> (Caramaschi & Rodrigues, 2003) #	DD	P	S	OE
<i>Hypsiboas faber</i> (Wied-Neuwied, 1821)	LC	P	M	TF, TS, BP, OE
<i>Hypsiboas pombali</i> (Caramaschi, Pimenta & Feio, 2004)	LC	P	L	TF, TS, OE, BP
<i>Hypsiboas semilineatus</i> (Spix, 1824)	LC	P	S	BP
<i>Itapotihyla langsdorffii</i> (Duméril & Bibron, 1841) #	LC	P	S	BP
<i>Phasmahyla spectabilis</i> Cruz, Feio & Nascimento, 2008 *	DD	S	L	TF, TS
<i>Phyllodytes</i> cf. <i>maculosus</i> Peixoto & Cruz, 1988 †	LC	B	L	TF, TS, OE
<i>Phyllodytes melanomystax</i> Caramaschi, Da Silva & Britto-Pereira, 1992†	LC	B	L	TF, TS, OE
<i>Phyllodytes wuchereri</i> (Peters, 1873)	DD	B	L	TF, TS, OE
<i>Phyllodytes</i> sp. 1	-	B	L	TF, TS, OE
<i>Phyllodytes</i> sp. 2†	-	B	L	TF, TS, OE
<i>Phyllodytes</i> sp. 3†	-	B	L	TF, TS, OE
<i>Phyllodytes</i> sp. 4†	-	B	L	TF, TS, OE
<i>Phyllomedusa burmeisteri</i> Boulenger, 1882	LC	P	L	TF, TS, OE
<i>Phyllomedusa nordestina</i> Caramaschi, 2006	DD	P	M	BP
<i>Phyllomedusa rohdei</i> Mertens, 1926	LC	P	M	BP
<i>Scinax argyreornatus</i> (Miranda-Ribeiro, 1926)	LC	P	S	BP, OE
<i>Scinax juncae</i> Nunes & Pombal, 2010	-	P	M	BP
<i>Scinax x-signatus</i> (Spix, 1824)	LC	P	S	BP
<i>Scinax eurydice</i> (Bokermann, 1968)	LC	P	-	TF, TS, BP, OE
<i>Scinax</i> sp. 1 #	-	P	S	BP
<i>Scinax</i> sp. 2 (gr. <i>rostratus</i>) #	-	-	-	BP
<i>Scinax strigilatus</i> (Spix, 1824)*	DD	S	S	TF, TS, OE
<i>Sphaenorhynchus prasinus</i> Bokermann, 1973 #	LC	P	S	BP
<i>Trachycephalus mesophaeus</i> (Hensel, 1867)	LC	P	S	TF, BP, OE
<i>Trachycephalus nigromaculatus</i> Tschudi, 1838* #	LC	-	-	TF, OE
HYLODIDAE				
<i>Crossodactylus</i> sp.*	-	S	-	TS, OE
LEPTODACTYLIDAE				
<i>Adenomera</i> cf. <i>thomei</i> Almeida & Angulo, 2006*	LC	-	-	TS, P
<i>Leptodactylus cupreus</i> Caramaschi, Feio & São-Pedro, 2008 * #	DD	P	-	BP
<i>Leptodactylus fuscus</i> (Schneider, 1799)	LC	P	M	BP, OE
<i>Leptodactylus</i> cf. <i>latrans</i> (Steffen, 1815)	LC	P	M	TS, BP, OE, P
<i>Leptodactylus mystaceus</i> (Spix, 1824)	LC	-	-	OE
<i>Physalaemus camacan</i> Pimenta, Cruz & Silvano, 2005	DD	P	M	P, OE, BP
<i>Physalaemus erikae</i> Cruz & Pimenta, 2004	LC	P	M	TF, P, OE, BP
MICROHYLIDAE				
<i>Chiasmocleis crucis</i> Caramaschi & Pimenta, 2003	DD	P	S	TF, P, BP

Family/Species	IUCN	Habitat	Mating Activity	Sampling Method
<i>Stereocyclops histrio</i> (Carvalho, 1954)* #	DD	P	S	BP
<i>Stereocyclops incrassatus</i> Cope, 1870	LC	P	S	P, OE, BP
ODONTOPHRYNIDAE				
<i>Odontophrynus carvalhoi</i> Savage & Cei, 1965* #	LC	S	S	OE
<i>Proceratophrys renalis</i> (Miranda-Ribeiro, 1920)* #	-	LL	-	OE
<i>Proceratophrys schirchi</i> (Miranda-Ribeiro, 1937)*	LC	S, LL	L	TF, TS, P, OE
PIPIDAE				
<i>Pipa carvalhoi</i> (Miranda-Ribeiro, 1937) #	LC	P	-	BP
SIPHONOPIDAE				
<i>Siphonops annulatus</i> (Mikan, 1820)*	LC	LL	-	TF, P, OE

Table 2. Number of anuran species found in areas of greatest richness within the Atlantic forest of Brazil and the state of Bahia (abbreviations for Brazilian states as follows: BA: Bahia; ES: Espírito Santo; SP: São Paulo; RJ: Rio de Janeiro). For studies providing the sampling effort in days and the total duration of the fieldwork we provided both.

Localities	N	Time Sampled	Area (km ²)	References
ATLANTIC RAIN FOREST				
Municipality of Santa Teresa (ES)	92	> 10 years	711	Almeida et al. 2011; Rödder et al. 2007
RPPN Serra Bonita (BA)	80	88 days (16 months)	20	This study
Reserva Biológica de Paranapiacaba (SP)	69	*	3.36	Verdade et al. 2009
Municipality of Rio de Janeiro (RJ)	68	> 5 years	1356	Izecksohn and Carvalho-e-Silva 2001
Estação Biológica da Boracéia (SP)	67	> 5 years	164.5	Heyer et al. 1990
Parque Estadual Carlos Botelho (SP)	65	76 days (1 year)	377.9	Forlani et al. 2010
Parque Estadual Turístico do Alto Ribeira (SP)	60	15 days (3 months)	357.1	Araujo et al. 2010
STATE OF BAHIA				
Serra da Jibóia and Serra do Timbó – Elísio Medrado and Amargosa	53	#	~ 100	Juncá 2006; Camardelli and Napoli 2012
Reserva Ecológica da Michelin – Ituberá	48	52 days (13 months)	9.75	Camurugi et al. 2010
Parque Estadual da Serra do Conduru – Ilhéus, Uruçuca and Itacaré	45	13 days (2 months)	92.7	Pimenta 2005
Reserva Sapiiranga – Mata de São João	37–40	36 days (8 months)	6	Juncá 2006; Bastazini et al. 2007
RPPN Veracel – Porto Seguro	39	4 days	80.9	Silvano and Pimenta 2003
Fazenda Vista Bela – Guaratinga	34	4 days	4.65	Silvano and Pimenta 2003
Projeto de Assentamento Zumbi dos Palmares – Camamu	32	4 days	18.3	Silvano and Pimenta 2003

* Mainly scientific data collections; # richness estimated based on the literature and scientific data collections (Camardelli and Napoli 2012) and 12 days (4 months) of fieldworks (Juncá 2006).



Figure 3. Anurans from the RPPN Serra Bonita, Bahia State, Northeastern Brazil. **a** *Brachycephalus pulex* **b** *Ischnocnema verrucosa* **c** *Ischnocnema* sp. 1 (gr. *parva*) **d** *Rhinella crucifer* **e** *R. granulosa* **f** *Vitreorana eurygnatha* **g** *V. uranoscopa* **h** *Haddadus binotatus* **i** “*Eleutherodactylus*” *bilineatus* **j** *Pristimantis* sp. 1 **k** *P. vinhai* **l** *Adelophryne* sp. **m** *Gastrotheca pulchra* **n** *Aplastodiscus ibirapitanga*; and **p** *A. cf. weygoldti*. Photos by I. R. Dias.

(Table 1). Two species deserve special attention: *Aplastodiscus cf. weygoldti* and *Allobates olfersioides*, respectively, are currently considered near threatened and vulnerable to extinction by the IUCN (2013). A recent scientific assessment of the extinction risk of the Brazilian fauna concluded that *Bokermannohyla lucianae* and *Phasmahyla spectabilis* can be considered as near-threatened with extinction (Subirá et al. 2012).



Figure 4. Anurans from the RPPN Serra Bonita, Bahia State, Northeastern Brazil. **a** *Bokermannohyla circumdata* **b** *B. lucianae* **c** *Dendropsophus anceps* **d** *D. bipunctatus* **e** *D. elegans* **f** *D. novaisi* **g** *D. giesleri* **h** *D. haddadi* **i** *D. minutus* **j** *Hypsiboas faber* **l** *H. semilineatus* **m** *Itapotihyla langsdorffii* **n** *Phasmahyla spectabilis* **o** *Phyllodytes wuchereri* and **p** *Phyllodytes* sp. 1. Photos by I. R. Dias.

Amongst the species recorded during mating activity ($n = 61$), 23 exhibited prolonged mating (37.7%) and the same number ($n = 23$) was observed to mate on few occasions during the study period, whereas 24.5% showed an intermediate mating period (Table 1). Thirty-five of the species observed during mating activity were found in temporary or permanent ponds, twelve in streams, six in plant litter, and eight species were seen vocalizing in bromeliads and epiphytes (Table 1).



Figure 5. Anurans from the RPPN Serra Bonita, Bahia State, Northeastern Brazil. (a) *Phyllomedusa burmeisteri* b *P. nordestina* c *P. rohdei* d *Scinax eurydice* e *Scinax* sp. 1 f *Scinax* sp. 2 (gr. *rostratus*) g *S. strigilatus* h *Sphaenorhynchus prasinus* i *Trachycephalus mesophaeus* j *T. nigromaculatus* l *Crossodactylus* sp. m *Adenomera* cf. *thomei* n *Leptodactylus cupreus* o *L. fuscus* and p *L. mystaceus*. Photos by I. R. Dias.

The highest variety of species was recorded through opportunistic encounters (50 species). The search at breeding sites resulted in the registration of an intermediary of sampled species (38 species), however, with a high number of exclusive species (18 species), even using a smaller effort hour/man. Data on efficacy of the methodologies used can be checked in Table 3.

A total of 16 species (20%) was only recorded once or twice during the sampling (Table 1). Most of these species are explosive breeder and were sampled after heavy rainfall at the study area.



Figure 6. Anurans from the RPPN Serra Bonita, Bahia State, Northeastern Brazil. **a** *Physalaemus camacan* **b** *P. erikae* **c** *Chiasmocleis crucis* **d** *Stereocyclops histrio* **e** *Stereocyclops incrassatus* **f** *Odontophrynus carvalhoi* **g** *Proceratophrys renalis* **h** *P. schirchi* and **i** *Siphonops annulatus*. Photos by I. R. Dias.

Table 3. Number total and exclusive species sampled by each sampling method with the respective sampling effort.

Sampling Method	Richness	Exclusive	Sampling Effort
Opportunistic encounters	50	7	-
Transect in the Forest	40	1	192 (hours/man)
Breeding pond sites	38	18	25 (hours/man)
Transect in the streams	36	2	54 (hours/man)
Pitfall	15	0	1728 (buckets/day)

There was a significant positive correlation between richness and monthly rainfall ($r = 0.65$, $DF = 10$, $p = 0.027$), but the same was not observed for the minimum ($r = -0.22$, $DF = 10$, $p = 0.49$) and the maximum ($r = -0.31$, $DF = 10$, $p = 0.33$) temperatures.

Discussion

Brazil harbors 946 amphibian species (Segalla et al. 2012) and near 543 of them have been recorded in the Atlantic Forest (Haddad et al. 2013). The State of Bahia is home to about 190 amphibian species. The amphibian community of RPPN Serra Bonita includes almost 15% of the overall species recorded in the Atlantic Forest and more than 40% of the species of Bahia State. Of the 20 anuran families that occur in Brazil (Frost 2014) only six

(most of them Amazonian species) have not been sampled at the Serra Bonita mountain (Allophrynidae, Alsodidae, Ceuthomantidae, Cycloramphidae, Dendrobatidae and Ranidae). These are expressive numbers, since such high diversity was detected concentrated in the 20 km² area forming the RPPN Serra Bonita.

The place known to show the largest amphibian richness in the Atlantic Forest is the municipality of Santa Teresa, Espírito Santo State, with 92 species (Rödder et al. 2007, Almeida et al. 2011). Yet, this amphibian diversity was obtained considering the entire municipality of Santa Teresa (711 km²), with a sampling effort of more than ten years, including records from different scientific collections. Thus, the amphibian diversity obtained in the RPPN Serra Bonita deserves special attention, as it comprises a smaller sampling area and effort. Even thus, the observed species richness is the second-highest ever recorded in a single study in the Atlantic Forest.

Most areas with high amphibian diversity in the Atlantic Forest are located in southeastern Brazil and are usually associated with mountainous locations (Heyer et al. 1990, Izecksohn and Carvalho-e-Silva 2001, Verdade et al. 2009, Forlani et al. 2010, Araujo et al. 2010). Aside from being the region where amphibians were better studied in Brazil, it concentrates the largest number of research groups working on amphibians (Rossa-Feres et al. 2011, Campos et al. in press).

Three out of the 80 species recorded at RPPN Serra Bonita (*Eleutherodactylus* “*bi-lineatus*”, *Pristimantis paulodutrai*, *P. vinhai*) are endemic to the State of Bahia (Juncá and Pimenta 2004, Peixoto and Pimenta 2004a, Pimenta and Juncá 2004) and another six (*Adelophryne mucronatus*, *Brachycephalus pulex*, *Chiasmocleis crucis*, *Physalaemus camacan*, *P. erikae*, *Stereocyclops histrio* and *Scinax strigilatus*) are endemic to southern Bahia State (Cruz and Pimenta 2004, Pimenta et al. 2005b, Pimenta et al. 2007, Targino and Wild 2009, Napoli et al. 2011a, Lourenço-de-Moraes et al. 2012, Forlani et al. 2013). *Phyllodytes wuchereri* and *Dendropsophus novaisi* are species known from less than three localities (Caramaschi et al. 2004, Peixoto and Pimenta 2004b), whereas *Bokermannohyla lucianae* was only known from the municipality of Una (Dias et al. 2011). Thus, 15% of the species are endemic to the Bahia State and considering the species identified at specific level or as “cf.”, 77.2% are endemic to the Atlantic Forest biome according to Haddad et al. (2013). Out of the 80 species recorded at the site, 29 were only recorded in the inner forests.

In this study we expand the geographic distribution of *Vitreorana uranoscopa* (Figure 3G) from Santa Teresa municipality, Espírito Santo State (Rödder et al. 2007) to the RPPN Serra Bonita (near 530 km north). Furthermore, two new species whose genera were only known to occur northward up to the Santa Teresa municipality were recently described from the State of Bahia. *Crossodactylodes septentrionalis* from Serra das Lontras (about 20 km from Serra Bonita in the municipality of Arataca) (Teixeira-Jr et al. 2013) and *Brachycephalus pulex* from RPPN Serra Bonita (Napoli et al. 2011a) both species being endemic to their type localities. To date, the two areas (municipality of Santa Teresa and RPPN Serra Bonita) have 33 species in common, but this number could even be larger. In addition, some species with northernmost

distribution known to Santa Teresa have been found in the state of Bahia (Freitas et al. 2004, Orrico 2010, Camurugi et al. 2010).

Much of the shared amphibians between the two areas are composed of typical lowland species or species associated to mountainous regions but with a wide distribution range. The Santa Teresa region is located within the northern range of the Serra da Mantiqueira. The montane areas of southern Bahia do not belong to this mountain chain. The presence of restricted endemisms in both regions, especially species living at higher altitudes, may indicate that historic geomorphological and climatic factors may have contributed to turn these mountain ranges into key areas of speciation, as has been suggested for the northern range of the Serra da Mantiqueira (Napoli 2005, Napoli et al. 2011b). However, molecular studies with phylogeographic approaches are needed to allow a better understanding of the role of the bahian mountain ranges in the diversification of the local anuran fauna.

Amongst the 80 species found in the area, 18 were cited without a specific name or were classified as similar or described in groups of species (see Table 1). Some of these belong to groups that are taxonomically complex and difficult to identify (e.g. *Adelophryne* spp.; *Crossodactylus* spp.; *Scinax* spp.). The increase in research and scientific advances involving the specimens collected during this study can reveal the existence of new species or identify the presence of species to date unknown to exist in the State of Bahia. A recent analysis of samples collected during the development of this inventory resulted in the description of *Brachycephalus pulex* (Napoli et al. 2011a). Moreover, new species may be described for the region.

The sampling effort of our study was focused on transects installed within streams and inner forest fragments. Thus, some habitats and environments were not intensively sampled, such as the *cabruças*, permanent and temporary ponds, as well as some areas of the RPPN complex that were not logistically feasible to be sampled. These areas had ponds and swamps in the inner forest, a feature that was not found in the areas sampled in our study. Future standardized effort including these environments might further enhance the richness of amphibians in the area.

In tropical regions, richness and mating activity are largely influenced by rainfall (Aichinger 1987, Duellman and Trueb 1994). Studies conducted in areas with seasonality detected a positive correlation between the sampled richness, rainfall and air temperature (Toledo et al. 2003, Santos et al. 2007, Kopp et al. 2010). Much of the amphibian community of Serra Bonita exhibited prolonged and intermediate mating activity (62% of spp.). According to Crump (1974) this is the pattern expected for non-seasonal tropical regions. As the area does not present a marked seasonality, most species meet suitable conditions allowing them to mate during much of the year.

In this study we detected a positive correlation between the sampled species richness and the monthly rainfall. In addition, it is likely that there was an increase in the number of species sampled during the months with higher rainfall indexes due to the appearance of explosive breeding species (e.g. *Dendropsophus novaisi*, *Stereocyclops incrassatus*, *Chiasmocleis crucis*, *Itapotihyla langsdorffii*, *Hypsiboas exastis*, *Scinax* sp. 1 and *Stereocyclops histrio*).

Final remarks

When comparing the amphibian species richness of RPPN Serra Bonita with that found at other sampled sites in the Bahia State, we notice a large disparity, since most locations exhibit less than half the number of species recorded in this study. This can be associated to the structural complexity of the sampled environment, which involves changes in temperature, rainfall, humidity and plant coverage along the altitudinal gradient in the study area, but also to the lack of systematic studies in most localities in the state of Bahia that still have large forest fragments and a mosaic of different ecosystems and biomes that need to be further explored from the scientific standpoint.

The largest Late Pleistocene refugium for amphibians has been estimated in southern Bahia and northern Espírito Santo states (Carnaval et al. 2009). During the quaternary glaciations, this zone of climatic stability probably allowed the coexistence and the diversification of a greater number of species in Serra Bonita, as compared to other places. Accordingly, the encounter of areas with a high concentration of amphibian species in this region was not unexpected. Serra Bonita may have been the first area to reveal such astonishing species richness, but other locations within the refugium have the same potential to support a high diversity of amphibians.

According to the IUCN (2008), the boundaries of the two municipalities of the studied RPPN (Camacan and Pau Brasil), are located within the area of geographical distribution of 26 other species (*Aparasphenodon bruno*i, *Chiasmocleis carvalho*i, *C. schubarti*, *Cycloramphus fuliginosus*, *Dendropsophus decipiens*, *D. nanus*, *Hypsiboas albopunctatus*, *Leptodactylus mystacinus*, *L. natalensis*, *L. spixi*, *L. viridis*, *Macrogenioglottus alipioi*, *Phyllodytes luteolus*, *Physalaemus crombiei*, *P. cuvieri*, *P. marmoratus*, *P. signifer*, *Pleurodema diplolister*, *Proceratophrys laticeps*, *Pseudopaludicola mystacalis*, *Scinax alter*, *S. fuscmarginatus*, *S. fuscovarius*, *Sphaenorhynchus palustris*, *S. pauloalvini* and *Thoropa miliaris*). These species have not been found during our field activities, but may potentially occur in the region. Most of them are typically encountered in lowland areas. Despite being a mountain with well preserved forests on its top several smaller forest fragments and abandoned cacao plantations still remain in the lowland areas of the RPPN, offering potential habitat for these species. Two recently described species (*Crossodactylodes septentrionalis* and *Dendrophryniscus oreites*) from Serra das Lontras (ca. 20 km from Serra Bonita) and the species *Gastrotheca recava* and *G. megacephala* (Teixeira-Jr et al. 2012, Teixeira-Jr et al. 2013, Recoder et al. 2010) possibly also may occur in the study area. Thus, we estimate that Serra Bonita may be the home for 100–110 amphibian species, representing one of the largest diversities for the group in the world.

The number of research institutes with graduate programs and professionals working on biodiversity in the State of Bahia has steadily increased during the last decade. The amount of information is expected to significantly increase in the coming years. Nonetheless, if we consider the vast extent of the territorial borders of Bahia, this increase in physical and human resources should be encouraged and further increased in order that we can better understand the diversity of anuran fauna in the State of Bahia.

A further step is to encourage funding agencies to sponsor scientific expeditions and medium and long term studies in the State – mostly basic studies – such as inventories of the local fauna.

Serra Bonita has a total area of 7500 hectares. One goal of the Uiraçu Institute is to protect about half that area. To date, about 2000 ha are under protection of the institute, which manages and protects the areas under a free lease agreement. Coupled with the wide diversity and endemism of amphibians found in the area, the finding of new species and new records for Bahia State make Serra Bonita a hotspot for amphibians within the Atlantic Forest hotspot and, consequently, a place for the implementation of priority conservation measures aiming the increase of the protected area.

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Appendix I

Specimens examined

Voucher specimens of the present study were deposited in the Museu de Zoologia da Universidade Estadual de Santa Cruz (MZUESC) at Universidade Estadual de Santa Cruz, municipality of Ilhéus, Bahia State, Brazil.

AROMOBATIDAE

Allobates olfersioides – MZUESC 8305.

BRACHYCEPHALIDAE

Brachycephalus pulex – MZUESC 8352, 8604-05, 10338-40.

Ischnocnema verrucosa – MZUESC 8323, 8464, 8829, 8993, 9090.

Ischnocnema sp. (gr. *parva*) – MZUESC 8057, 8059, 8234, 8312-13, 8366-68, 8460-61.

BUFONIDAE

Rhinella crucifer – MZUESC 8428-29, 8310.

Rhinella granulosa – MZUESC 9016.

Rhinella hoogmoedi – MZUESC 8380, 8601, 8904.

CENTROLENIDAE

Vitreorana eurygnatha – MZUESC 8308, 8373-75, 8441-42, 8520, 8911.

Vitreorana uranoscopa – MZUESC 8630, 9000-01.

CRAUGASTORIDAE

Haddadus binotatus – MZUESC 8045, 8327-28, 8421, 8435, 8437, 8611, 8906, 8909, 8927.

“*Eleutherodactylus*” *bilineatus* – MZUESC 8359, 8457, 8616-17, 8999.

Pristimantis sp. 1 – MZUESC 8058, 8133, 8370-72, 8530, 8619-20, 8841-42, 9084-85.

Pristimantis sp. 2 – MZUESC 13272-73.

Pristimantis vinhai – MZUESC 8115, 8332, 8338, 8382, 8536-37, 8542, 8608, 8621, 8629.

ELEUTHERODACTYLIDAE

Adelophryne mucronatus – MZUESC 8458, 8068.

Adelophryne sp. – MZUESC 8049, 8358, 8447, 8838-40.

HEMIPHRACTIDAE

Gastrotheca sp. – MZUESC 8827.

Gastrotheca pulchra – MZUESC 8120, 8314, 8463, 8828.

HYLIDAE

Aplastodiscus cf. *weygoldti* – MZUESC 8139, 8443, 8531-32, 8532, 8572, 8612-13, 8830-34.

Aplastodiscus ibirapitanga – MZUESC 8307, 8318, 8369, 8571, 8598-99, 8600, 8994, 9086.

Bokermannohyla circumdata – MZUESC 8360-61, 8439-40, 8526-29, 8618, 8826, 9074-76.

Bokermannohyla lucianae – MZUESC 8295-97, 8995.

Dendropsophus anceps – MZUESC 8419, 8857, 9048-49.

Dendropsophus bipunctatus – MZUESC 10332-34.

Dendropsophus branneri – MZUESC 8474-75.

Dendropsophus elegans – MZUESC 8849-50.

Dendropsophus giesleri – MZUESC 8590-92, 8855, 10335.

Dendropsophus haddadi – MZUESC 8362, 8476, 8568-69, 8577-82, 9087.

Dendropsophus novaisi – MZUESC 8565, 9025-27.

Dendropsophus minutus – MZUESC 8853, 9005.

Dendropsophus aff. *oliveirai* – MZUESC 8477-78, 8566-67.

Hypsiboas albomarginatus – MZUESC 8471, 8854, 8903.

Hypsiboas crepitans – MZUESC 8899.

Hypsiboas faber – MZUESC 8326, 8379.

Hypsiboas pombali – MZUESC 8302, 8378, 8631, 9018.

Hypsiboas semilineatus – MZUESC 13268-71.

Itapotihyla langsdorffii – MZUESC 9023-24.

Phasmahyla spectabilis – MZUESC 8150-51, 8294, 8298, 8303.

Phyllodytes wuchereri – MZUESC 8134, 8319, 9052.

Phyllodytes sp. 1 – MZUESC 8135-36, 8574.

Phyllomedusa burmeisteri – MZUESC 8309, 8470.

Phyllomedusa nordestina – MZUESC 9003-04.

Phyllomedusa rohdei – MZUESC 8846, 9015.

Scinax argyreornatus – MZUESC 8473, 8588-89.

Scinax juncae – MZUESC 8856, 13056-13068

Scinax x-signatus – MZUESC 8573, 8593-96.

Scinax eurydice – MZUESC 8041, 8113, 8432, 8467, 8603, 8847-48.

Scinax sp. 1 – MZUESC 8570, 8584-87.

Scinax sp. 2 (gr. *rostratus*) – MZUESC 8573.

Scinax strigilatus – MZUESC 8365, 8623-24, 8626, 8996, 9053, 9081, 9083.

Sphaenorhynchus prasinus – MZUESC 8597.

Trachycephalus mesophaeus – MZUESC 8315, 9019.

Trachycephalus nigromaculatus – MZUESC 8299, 8905.

HYLODIDAE

Crossodactylus sp. – MZUESC 8056, 8121-22, 8521.

LEPTODACTYLIDAE

Adnomera cf. *thomei* – MZUESC 8138, 8317, 8364.

Leptodactylus cupreus – MZUESC 9041.

Leptodactylus fuscus – MZUESC 9002, 9017.

Leptodactylus cf. *latrans* – MZUESC 8915.

Leptodactylus mystaceus – MZUESC 8040.

Physalaemus camacan – MZUESC 9045-47.

Physalaemus erikae – MZUESC 8423, 9006, 9042-44.

MICROHYLIDAE

Chiasmocleis crucis – MZUESC 9028–29, 9031–34, 9036.

Stereocyclops histrio – MZUESC 9037-40.

Stereocyclops incrassatus – MZUESC 8422, 9020-22.

ODONTOPHRYNIDAE

Odontophrynus carvalhoi – MZUESC 8564.

Proceratophrys renalis – MZUESC 10341.

Proceratophrys schirchi – MZUESC 8152, 8300, 8468-69, 8602, 10342-45.

PIPIDAE

Pipa carvalhoi – MZUESC 7360.

SIPHONOPIDAE

Siphonops annulatus – MZUESC 8376, 8459, 8913, 9056, 9070.