

Supplementary material to:

A new species of crown-of-thorns sea star, *Acanthaster benziei* sp. nov. (Valvatida: Acanthasteridae), from the Red Sea

GERT WÖRHEIDE^{1,2,3*}, EMILIE KALTENBACHER¹, ZARA-LOUISE COWAN¹ & GERHARD HASZPRUNAR^{2,4}

1 Department of Earth and Environmental Sciences Palaeontology and Geobiology, Ludwig-Maximilians-Universität München, Munich, Germany

2 GeoBio-Center, Ludwig-Maximilians-Universität München, Munich, Germany

3 SNSB-Bavarian State Collection of Palaeontology and Geology, Munich, Germany

4 SNSB-Zoological State Collections, Munich, Germany

** Corresponding author: woerheide@lmu.de*

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Abstract. A new species of crown-of-thorns sea star (CoTS), *Acanthaster benziei* n. sp., is described based on four specimens collected from Saudi Arabia's Red Sea coast where it inhabits coral reefs. Species delimitation from congeners in the species complex, i.e., *Acanthaster planci*, *Acanthaster mauritiensis* and *Acanthaster* cf. *solaris*, is primarily based on distinct and diagnostic mitochondrial DNA sequence regions. Species separation of *Acanthaster benziei* is additionally justified due to diagnostic morphological characters: fewer arms; narrower and thinner spines; fanned spine tips in primary and latero-oral spines; a wider tip or tapering shape in circumoral spines; and rhombus-shaped oral pedicellariae.

Additional files:

Zootaxa_AK46_Alignment.fasta – 632 bp partial COI alignment of 84 *Acanthaster* sequences.

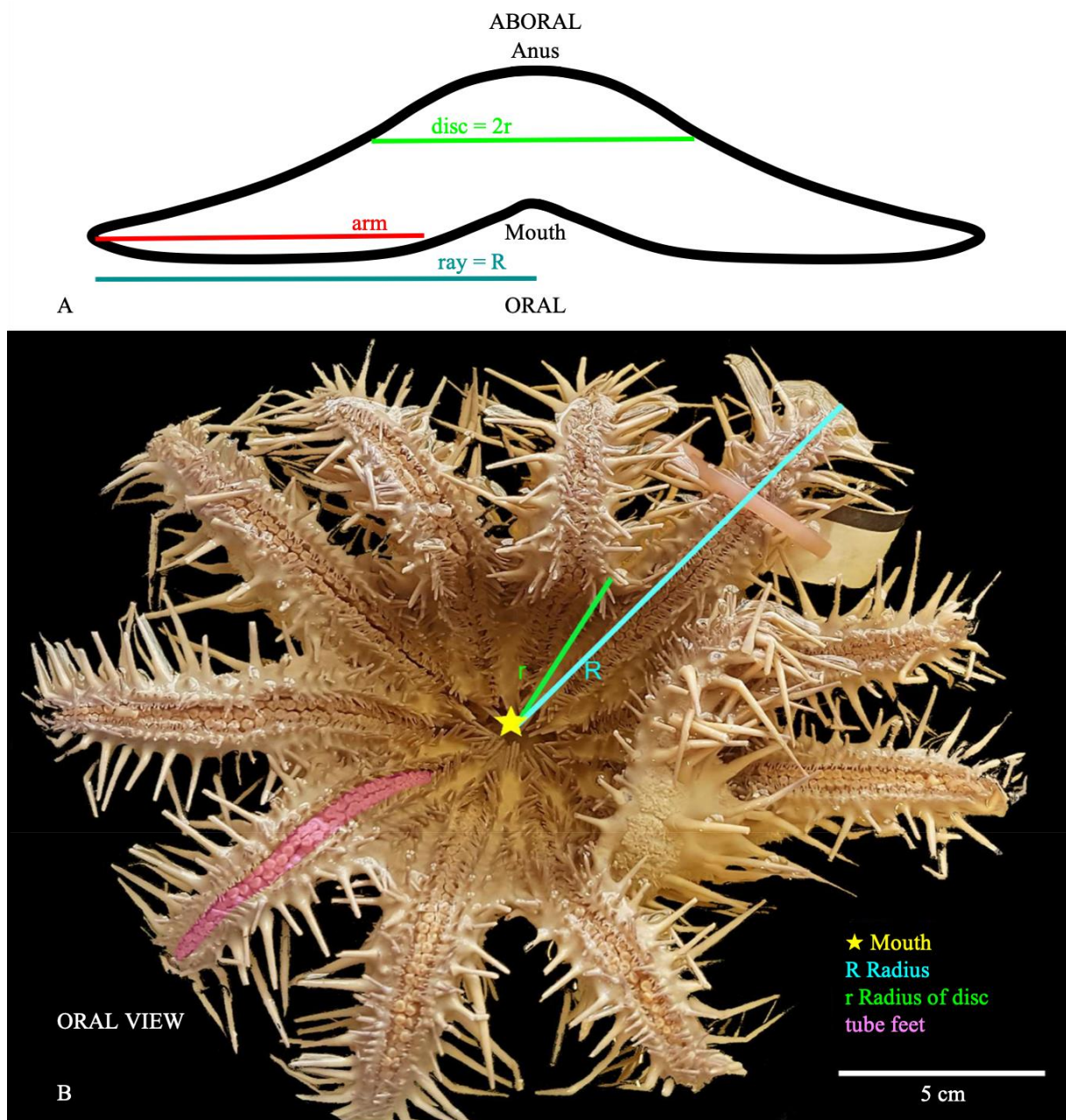


Figure S1. Explanatory pictures of the overall morphology and measurements, indicating how measurements were taken. **A:** Schematic drawing of a sea star from the side (without spines). **B:** Photograph of the oral side of *Acanthaster benziei* sp. nov. (GW4081) with the aboral side of one arm visible. Important morphological features are highlighted in different colours.

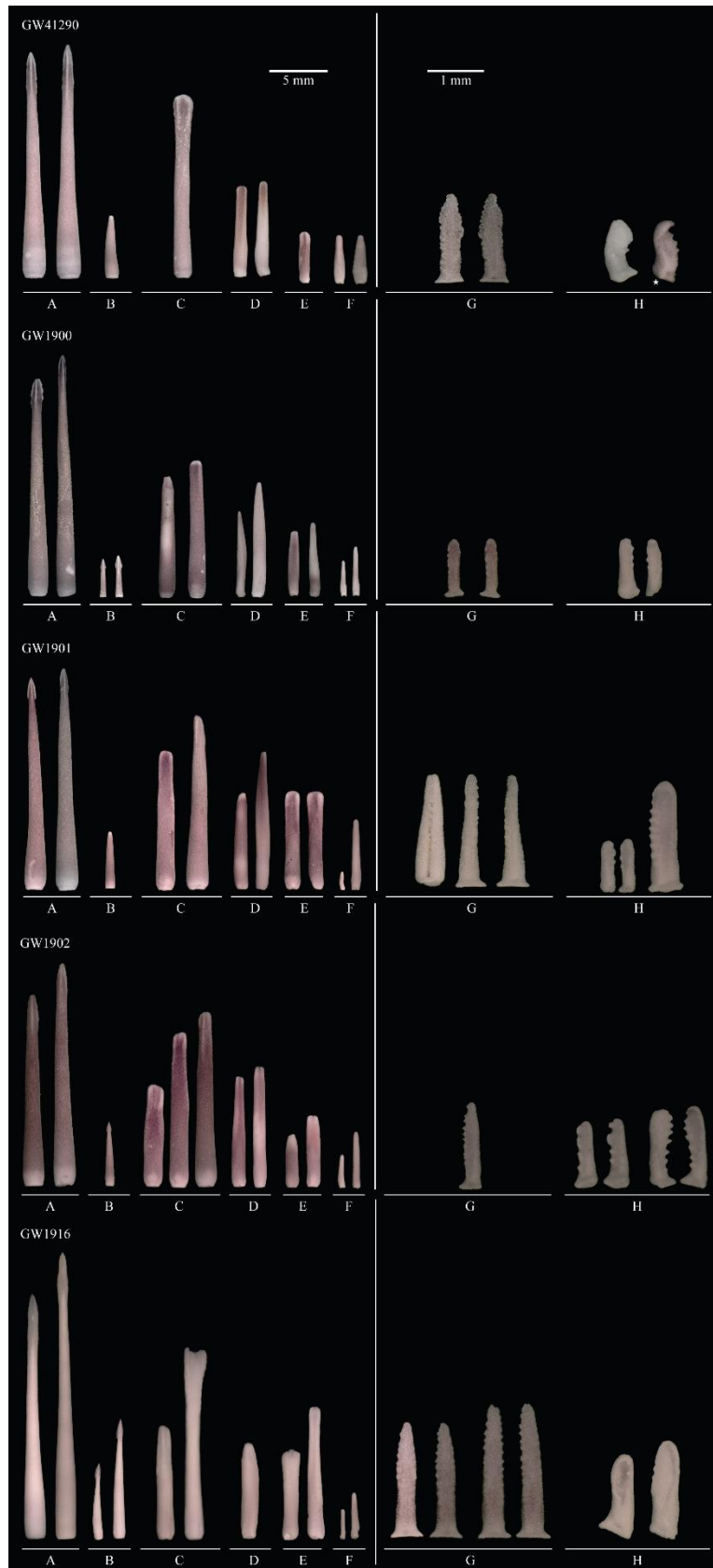


Figure S2. *Acanthaster planci* (A–B) Aboral spines, (C–F) oral spines and (G–H) pedicellariae of five adult specimens from the Northern Indian Ocean clade. **A:** Primary spines; **B:** Secondary spines. **C:** Latero-oral spines. **D:** Circumoral spines. **E:** Oral spines. **F:** Subambulacral spines. **G:** Aboral pedicellariae. **H:** Oral pedicellariae. Star (☆) indicates a side view.

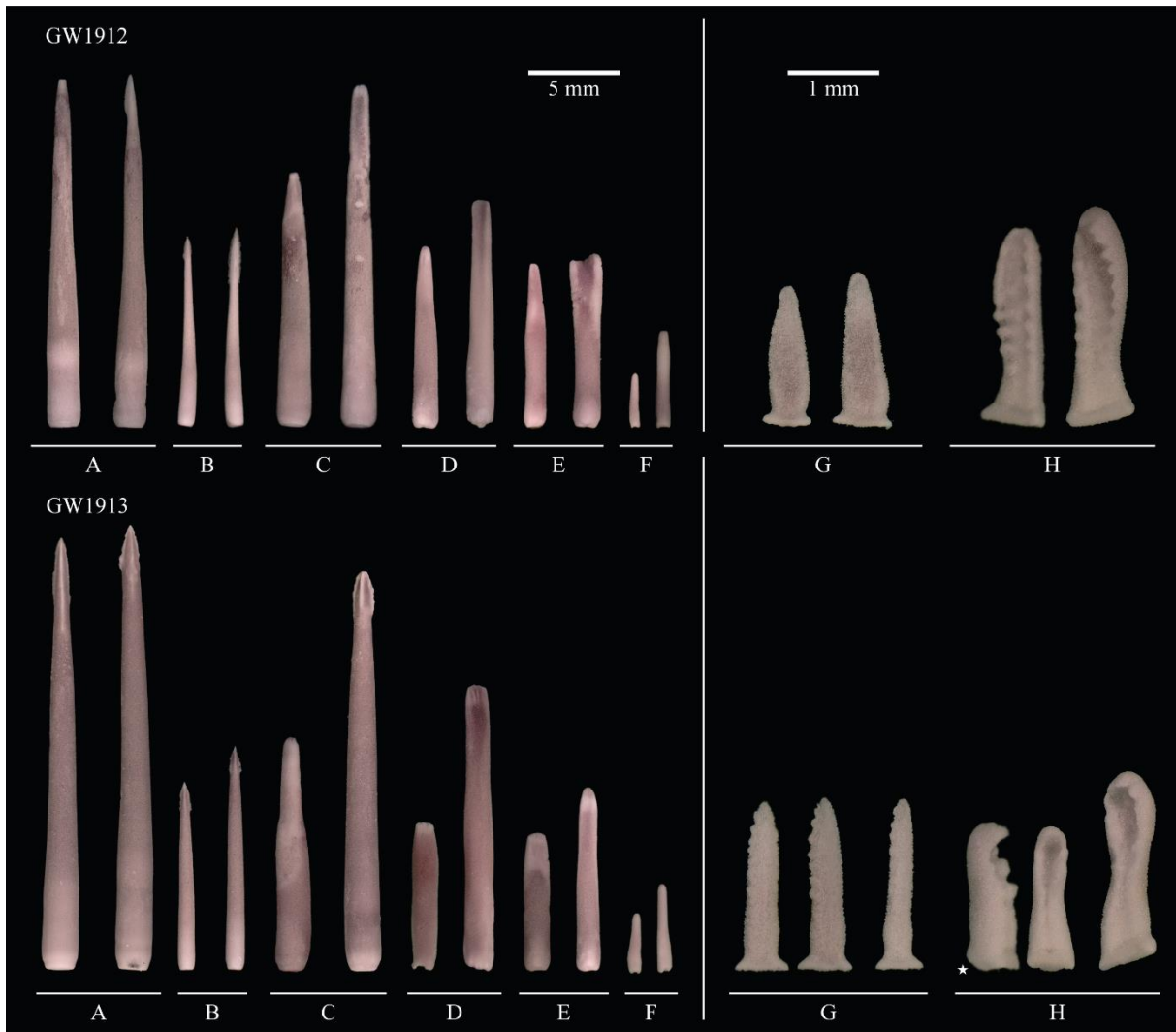


Figure S3. *Acanthaster mauritiensis* (A–B) Aboral spines, (C–F) oral spines and (G–H) pedicellariae of two adult specimens from the Southern Indian Ocean clade. **A:** Primary spines; **B:** Secondary spines. **C:** Latero-oral spines. **D:** Circumoral spines. **E:** Oral spines. **F:** Subambulacral spines. **G:** Aboral pedicellariae. **H:** Oral pedicellariae. Star (☆) indicates a side view.

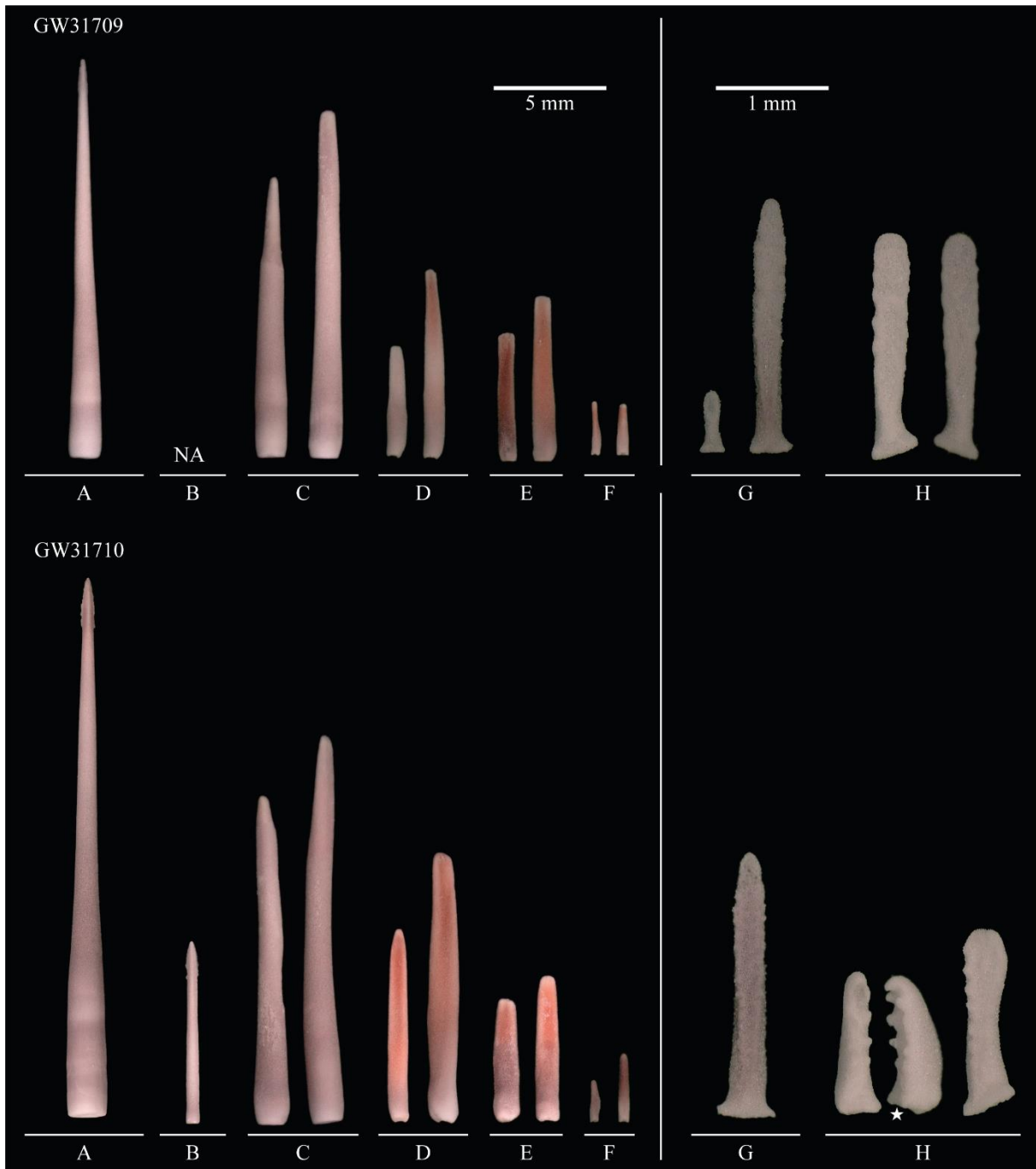


Figure S4. *Acanthaster cf. solaris* (A–B) Aboral spines, (C–F) oral spines and (G–H) pedicellariae of three adult specimens of the Pacific Ocean clade. **A:** Primary spines; **B:** Secondary spines. **C:** Latero-oral spines. **D:** Circumoral spines. **E:** Oral spines. **F:** Subambulacral spines. **G:** Aboral pedicellariae. **H:** Oral pedicellariae. Star (☆) indicates a side view. No secondary spines were photographed for individual GW31709.

Supplementary Table 1

Species	<i>A. benziei</i> sp. nov.	<i>A. planci</i>	<i>A. mauritiensis</i>	<i>A. cf. solaris</i>	<i>A. brevispinus</i>
Literature used	this publication; type series excluding juvenile specimen GW4266	Walbran 1987; Moran 1990	de Loriol 1885; Grindley 1968; Gigou 2011	Schreber 1793; Grey 1840; Fisher 1917; Motokawa 1986, Nakamura 1986; Guenther 2007; Caso 1970, 1974	Fisher 1917
Sampling Locality	Saudi Arabia	Australia, Townsville (may therefore rather represent <i>A. cf. solaris</i>)	Mauritius; Mozambique; Mayotte	Philippines (?); Japan; Australia; Hawaii	Sirun Island
Distribution (Haszprunar et al. 2017)	Red Sea	North Indian Ocean	South Indian Ocean	Pacific	
Arms	11–14	8–21	11–22	9–22	14–16
# Arms, mean	12.25	16	15.9	15.41	15
Radius [cm] R	9.1–12.5	25–40	3.25–35	6–26.4	9
R mean [cm]	10.73	33.3	26.17	14.51	
Radius [cm] r	mean: 5.8–6.5	x	10 (for R:18.5)	Mean: 5.8 (?) 3.1–8.5	5.1
R:r ratio [x:1]	1.57–2.06	x	1.85	1.65 or 2.18 or 2.5 (?) or 2.2 (Madsen 1955)	1.76

Spines	<p>subambulacral: 4 grouped, two long (3 mm) and two short (1 mm) or all off different length (1–3 mm), getting shorter towards the tip of a ray, always associated with one tube foot;</p> <p>oral: blunt tip with furrow, sometimes “heart-shaped”, same length (5 mm), can be two rows, one isolated spine at the oral marks the beginning of the outer row, interfinger with the ones of the next ray;</p> <p>circumoral: longer than oral spines (8–10 mm), two facing the oral;</p> <p>latero-oral: interfinger at the disc with the ones of the next ray, max. 20 mm at the arms, min. 5 mm at the disc</p>	<p>subambulacral, circumoral/oral/latero-oral = intermediate, oral</p>	<p>subambulacral: 4 spines grouped together, one or two longer than others (max. 7 mm), unregularly: sometimes two long, two short, sometimes all of different length, spines are smooth and flat, lightly conic and blunt, sometimes with furrow, associated with pedicellariae;</p> <p>oral: longer than subambulacral (9–10 mm), thicker and more robust, cylindrical, flat with extreme furrow and a dense granulation, in up to 4 rows that get longer and more pointed; interradial on disc with 10–12 rows of spines, thick, cylindrical, max 10mm, less in direction of mouth</p>	<p>general: flat, bend over to cover mouth + ambulacral grooves;</p> <p>latero-oral: 9–20 mm, on lateral edge of arms, crossed with ones of adjacent arm, round in proximal part, but in distal oval with furrow on tip, length increases towards distal end;</p> <p>oral: 5–7 mm, 2 rows on arms with first one also fringing the subambulacral a groove second btw the first row and the row of latero-oral spines, blunt tip, flattened cross-sectional shape (cylinder), covering the main area, one flattened surface facing the mouth with furrow on tip - ambulacral furrow spinelets = oral spines: 2/3, nearly equal and divergent, second</p>	<p>subambulacral: 1-3 grouped, middle one longest, short and tapered, longest still shorter than plate;</p> <p>oral: as long as two plates, tapered + blunt, sometimes grooved;</p> <p>latero-oral/intermediate: 2/3 the length of disc towards tip</p>
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				<p>articulation about one-third the length from base;</p> <p>Circumoral: 7–11 mm, no furrow, one single row;</p> <p>Subambulacra l: 1–4mm, fringe the margin of ambulacral grooves, no furrow, 2 long and 1 short on one ossicle, flat and wider surface of spine faces the groove, tapered and grooved at tip; spines on arms are longer than spines on the disk, actinal intermediate: tapered and grooved at tip</p>	
<p>dorsal (after abactinal, aboral)</p>	<p>primary: a pointy needle-like tip, 6–27 mm on disc, 27–33 mm on the arms;</p> <p>secondary aboral spines: if not absent, not distinguishable from the primary aboral spines</p>	<p>primary: long barbed,</p> <p>secondary: shorter smooth</p>	<p>abactinal: bended spines that are for the size of the animals not very long (R19.5: 25-30mm, R7.5: 4–7mm, R3.25: 3–4mm); they are joint at some distance from the base or rest on a high conical base with perforated edge as articular surface of the spine and are flexible; the spines are granulated with pointed or triangulated tips; spines on arms are longer in seven rows</p>	<p>general: cylindrical + sharp tips, movable joint to pedicle;</p> <p>primary aboral: 16–18 mm or 25–35 mm (disc) up to 45 mm (ray), tappers towards tip, triangular tip with one sharp edge like a scalpel, mounted on pedicles both</p>	<p>very numerous + dense, slightly tapered, blunt;</p> <p>spinelets: skin covered, <2mm, sometimes 3-edged tip, sometimes granules; 5-10mm; bigger towards tip, fine granulation covered by skin, nearly no pedicle</p>

			with blunt tips on the sides with longitudinal lamellae, spines seem to branch 1.7 cm with pedicle; arms: stouter, longer, 1/5 length of arm+granular	with small holes, toxic; secondary aboral: 7–11 mm, only on the disk, less than primary, toxic, shorter on disc than arm (spindle shaped)	
Pedicellariae	<p>Abactinal: 1–3.5 mm length on disc, <2 mm length on arm, lacking on the distal part of the arms, flexible, slender, pointy tips, elementary;</p> <p>actinal: associated with oral spines, 1–1.5 mm</p>	<p>elementary, actinal and abactinal; adambulacral: pits; abactinal embedded</p>	<p>abactinal: long and slender</p>	<p>abactinal: long and slender (0.2–1.5; 2.5 mm), associated with primary spine, only one type with two straight elongated equal valves, supported by basal ossicle, abundance variable, rare on arms, spiniform;</p> <p>Caso: two types</p> <p>1: with distal half split in spoon shape and denticulated and proximal half long and straight;</p> <p>2: narrow, sharp, fine and narrow tips; large variability between these two types</p> <p>actinal: slightly tapered, two-</p>	<p>abactinal: small, 2 or 3-jawed (0.5–0.75 mm), thick jaws (nearly as broad as high), round-tipped;</p> <p>ambulacral: 2-jawed, same length as spine, oriented dorsal and ventral</p>

				<p>jawed/elementary, 3/4 as long as longest furrow spine, associated with first row of oral spines,</p> <p>Caso: 1–3 on each ambulacral plate/ambulacral spine, small spiniform, in some spec. extraordinarily with wide shells</p>	
Surface	<p>disc: many papulae, no clear arrangement, none around after, madreporites roundish + hard plates + convex surface, arranged in a circle around the after;</p> <p>arms: no papulae on distal part, harder + smooth, no granules observed</p>	<p>madreporites embedded, dorsal: granules in surface layer (subspherical, elliptical); actinal intermediate, primary abactinal, basal on spines: encrusting granules</p>	granular	<p>no granules on spines, granular skin</p> <p>Caso: granular at spines, papules: on the back of a plate and the rays and on their sides, in living specimens blueish or reddish in alcohol fixation</p>	<p>abactinal (disc): granulation is spaced+fine -> coarse+dense towards margin;</p> <p>actinal: coarse granulation, also on base of spines</p>
Color	gray-green to gray-purple (Haszprunar 2017)	purplish blue, "electric-blue"	greenish with orange spines, light blue-rusty (Haszprunar 2017)	gray-green to gray-purple (Haszprunar 2017), end of thorns reddish (Caso 1970)	mostly red/rusty to dark-blueish
Ossicles	actinal	intermediate: with spines, 3–4, forming "actinal fields"; adambulacrals; ambulacrals: first		oral: characteristically shaped, proximal fragmented, distal ends	narrow mouth plates

		one largest and adjacent to body cavity; one terminal; interbrachial/interradial: btw oral and first ambulacral, between proximal ossicles of arms		also elongated with a small bump --> birds beak: base is heel shaped, dorsal with double groove oriented towards the mouth and follows the length of the plate, margins surrounded by spines; distal: variation in shape and size (4–17 mm); marginal: robust bases (8–15 mm)	
abactinal		primary and secondary form meshwork; secondary: plate/bar-shaped, support madreporites; primary: spines		each spine on robust basal plate; pedicles on the crossings of the ossicles, pedicel and polygonal plates of framework have flower-shaped relief where it is mounted as depression, pedicles incline more towards distal end	mesh very narrow
# Madreporites	4–6	3–16	7	4–16	3–5
Addition al		1–6 anuses		1–6 anuses	

Additional references

(for Supplementary table 1)

- Caso, M.E. (1970) External Morphology of *Acanthaster planci* (Linnaeus). *Anales del Instituto de Biología, Universidad Nacional Autónoma de México*, 41, 63–78.
- Caso, M. E. (1974) Morfología externa de *Acanthaster planci* (Linnaeus). *Journal of the Marine Biological Association of India*, 16 (1), 83–93.
- Fischer, W.K. (1917) New starfishes from the Philippines and Celebes. *Proceedings of the Biological Society of Washington*, 30, 89–93.
- Gigou, A. (2011) Les étoiles de mer épineuses *Acanthaster planci* du lagon de Mayotte: des explosions démographiques de plus en plus fréquentes. Report, available at https://www.academia.edu/download/7215362/2011_01_gigou_acanthaster_vfinale_redannexes.pdf
- Gray, J.E. (1840) A synopsis of the genera and species of the class Hypostoma (Asterias, Linnaeus). *Annals of the Magazine of Natural History*, 6, 275–290.
- Grindley, J.R. (1963) A specimen of the asteroid *Acanthaster planci* (Linnaeus) from the Mozambique coast. *Durban Museum Novitates*, 6, 264–268.
- Guenther, J., Heimann, K. & de Nys, R. (2007) Pedicellariae of the crown-of-thorns sea star *Acanthaster planci* are not an effective defence against fouling. *Marine Ecology Progress Series*, 340, 101–108.
- Nakamura, R. (1986) A morphometric study on *Acanthaster planci* (L.) populations in the Ryukyu Islands. *Galaxea*, 5, 223–237.