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Echinoderes antalyaensis sp. nov. (Cyclorhagida: Kinorhyncha) from Antalya, Turkey, Levantine Sea, Eastern Mediterranean Sea

Hiroshi Yamasaki[1,2,4] and Furkan Durucan[3]

[1] *Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity, Invalidenstr. 43, D-10115 Berlin, Germany*
E-mail: h.yamasaki@meiobenthos.com
[2] *Senckenberg am Meer, Abt. Deutsches Zentrum für Marine Biodiversitätsforschung DZMB, Südstrand 44, D-26382 Wilhelmshaven, Germany*
[3] *Işıklar Caddesi No 16, 17 TR-07100 Antalya, Turkey*
[4] *Corresponding author*

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A new kinorhynch species, *Echinoderes antalyaensis* sp. nov., is described based on specimens from Antalya, Turkey, eastern Mediterranean Sea. *Echinoderes antalyaensis* sp. nov. is characterized by the presence of a middorsal acicular spine on segment 4, laterodorsal tubes on segment 10, lateral accessory tubes on segments 5 and 8, lateroventral tubes on segment 2, and lateroventral acicular spines on segments 6–8, and by the absence of type-2 glandular cell outlets. The morphology of the ornaments of outer oral styles among Echinoderidae and the value of the character in the future taxonomic studies are discussed. The new species is the third *Echinoderes* species from Turkish waters, and the 14th species from the Mediterranean Sea.

Key Words: Mud dragon, new species, taxonomy, Echinoderidae, oral style, morphology.

Introduction

Kinorhynchs of the genus *Echinoderes* are marine and brackish-water meiobenthic species with their body size in the adult stage varying from 152 µm in *Echinoderes charlotteae* Sørensen *et al.*, 2016 to 528 µm in *Echinoderes rex* Lundbye *et al.*, 2011 (Lundbye *et al.* 2011; Sørensen *et al.* 2016). The genus is the most species-rich taxon within Kinorhyncha, comprising more than 100 valid species (Neuhaus 2013; Sørensen 2013; Grzelak and Sørensen 2018; Herranz *et al.* 2018). While *Echinoderes* is found worldwide from polar to tropical regions and from shallow to deep-sea bottoms, the faunistic investigations have been intensively done only in a small part of the world and most regions have been only sporadically investigated or completely untouched. The recent expeditions in such areas still find many new species and the number of the species is increasing nowadays (*e.g.*, Grzelak and Sørensen 2018; Herranz *et al.* 2018; Yamasaki *et al.* 2018a, b).

The Mediterranean Sea is one of the better-studied regions, with records of 13 species of *Echinoderes* (Zelinka 1928; d'Hondt 1973; Higgins 1978; Sánchez-Tocino *et al.* 2011; Sánchez *et al.* 2012; Dal Zotto and Todaro 2016; Sönmez *et al.* 2016; Yamasaki *et al.* 2018a). Especially in the western and middle part of the Mediterranean Sea, comprehensive investigations were done around the coast of the Iberian Peninsula by Sánchez *et al.* (2012), in the Bay of Naples and in the Gulf of Trieste by Zelinka (1928), and around the Italian coast by Dal Zotto and Todaro (2016). In comparison to these areas, the eastern part of the Mediterranean Sea has been scarcely studied. Just very recently, Sönmez *et al.* (2016) reported *Echinoderes* cf. *gerardi* Higgins, 1978 and *Echinoderes* cf. *bispinosus* Higgins, 1982 from the western Turkish coast, and Yamasaki *et al.* (2018a) reported *Echinoderes multiporus* Yamasaki *et al.*, 2018 from the Eratosthenes Seamount, off Cyprus and one undescribed species from the Anaximenes Seamounts, off Turkey. In addition, *Cephaloryncha flosculosa* Yıldız *et al.*, 2017 which belongs to Echinoderidae was described from the southwestern coast of Turkey in Yıldız *et al.* (2017).

In this study, we describe a new *Echinoderes* species collected from Antalya, southern part of Turkey, eastern Mediterranean Sea. The new species is the third *Echinoderes* species from the Turkish coast, and the 14th representative from the Mediterranean Sea.

Materials and Methods

Meiobenthic organisms were obtained from red algae, *Laurencia obtusa*, on sandy bottom at 3 m depth off the Bilem Beach, Antalya, Turkey (36°51′17″N, 30°44′38″E) on 20 October, 2015. The meiobenthic sample was preserved in 70% ethanol, and kinorhynchs were sorted from the sample under a stereo microscope Nikon SMZ.

Five specimens were mounted as glycerol-paraffin slides on Cobb aluminum frames for light microscopy (LM). LM specimens were observed with a Zeiss Axioskop 50 microscope equipped with Nomarski differential interference contrast, an Optovar 1.6x, objectives Plan-Neofluar 63/0.90 Korr. and 100/1.30 oil, and a camera lucida for drafts of line illustrations and measurements. Final line illustrations were drawn with Adobe Illustrator CS6 based on the drafts. Specimens were photographed with a Zeiss AxioCam MRc5 and objectives Plan-Apochromat 20x/0.60 and 100x/1.40 Ph3 oil attached to a microscope Zeiss Axioplan 2 mot.

One specimen for scanning electron microscopy (SEM) was transferred from ethanol to distilled water through a graded series of ethanol, postfixed with OsO_4 in 0.05 M phosphate buffer (pH = 7.3) with 0.3 M sodium chloride and 0.05% sodium azide for 2.5 hours, dehydrated through a graded series of ethanol, critical-point dried with a BalTec CPD 030, mounted on aluminum stubs, sputter-coated with gold-palladium with a Polaron SC 7640, and observed with a Zeiss EVO LS 10 scanning electron microscope.

The terminology follows Neuhaus and Higgins (2002), Sørensen and Pardos (2008), and Neuhaus (2013). All specimens have been deposited in the Museum für Naturkunde Berlin (= ZMB, former Zoological Museum Berlin), Germany and catalogued in the collection "Vermes" in the "Generalkatalog Freilebende Würmer".

Systematics

Class **Cyclorhagida** Sørensen *et al.*, 2015
Order **Echinorhagata** Sørensen *et al.*, 2015
Family **Echinoderidae** Zelinka, 1894
Genus ***Echinoderes*** Claparède, 1863
Echinoderes antalyaensis sp. nov.
(Figs 1–8; Tables 1, 2)

Material examined. Holotype: Adult male (ZMB 11673), collected from red algae, *Laurencia obtusa*, at 3 m depth off the Bilem Beach, Antalya, Turkey (36°51′17″N, 30°44′38″E), mounted as glycerol-paraffin slide on a Cobb aluminum frame. Paratypes: two adult females and two adult males (ZMB 11674–11677), all collected together with the holotype. Additional material: one adult male, collected together with the holotype, mounted on an aluminum stub for SEM observations (ZMB 11678).

Diagnosis. *Echinoderes* with middorsal acicular spine on segment 4 only; laterodorsal tubes on segment 10; lateral accessory tubes on segments 5 and 8; lateroventral tubes on segment 2; lateroventral acicular spines on segments 6–8; without type-2 glandular cell outlets.

Description. Adult with head, neck, and eleven trunk segments (Figs 1A, B, 2A, B, 3A, 4A). Measurements presented in Table 1. Positions of cuticular structures (sensory spots, glandular cell outlets, spines, tubes, and sieve plates) summarized in Table 2.

Head consisting of retractable mouth cone and introvert (Figs 2A, B, 3A). Distal part of mouth cone with pharynx crown, five inner oral styles in each of ring-03 and ring-02, and one ring of nine outer oral styles (Figs 2B–E, 5). Inner oral styles of ring-01 not examined (they covered by ring-02 and ring-03 inner oral styles and ornaments of basal outer oral styles; Fig. 2D). Inner oral styles visible both in SEM and LM specimen with part of pharynx artificially protruded, but number of styles countable only in SEM (Fig. 2C–E). Each outer oral style consists of triangular distal and rectangular basal part (Fig. 2D, E). Outer oral styles with fringe at their bases composed of three to four long spinose processes which bifurcated at its tip. One pair of additional long spinose processes originating slightly more anteriorly and laterally on either side of each outer oral style (Fig. 2D, E). Introvert composed of six rings of spinoscalids and one ring of trichoscalids (Figs 3A, B, 5). Ring 01 with ten primary spinoscalids consisting of one basal sheath and one distal end piece (Fig. 3A, B). Each basal sheath with three overlapping fringes. Proximal fringe composed of four short projections between two long lateral ones. Middle fringe with three medial projections, and distal fringe with six to seven branched projections. Distal end pieces of primary spinoscalids longest within all spinoscalids. Rings 02 and 04 with 10 spinoscalids; rings 03 and 05 with 20 spinoscalids (Figs 3A, B, 5). Each spinoscalid of rings 02–05 with basal sheath and end piece. Rings 06 not examined in detail, but with at least six spinoscalids. Six trichoscalids attached with trichoscalid plate in sectors 2, 4, 5, 7, 8, and 10 (Figs 3A, B, 5). Each trichoscalid covered with long hairs on entire surface.

Neck with 16 placids (Figs 1A, B, 3A, 5). Midventral placid broadest. Remaining placids similar in size. Two trichoscalid plates present ventrally and four dorsally.

Segment 1 consisting of complete cuticular ring (Fig. 1A, B). This and following ten segments with thick pachycyclus at anterior margin of each segment. Sensory spots in subdorsal, laterodorsal, and ventrolateral position (Figs 1A, B, 4B, 6A, E). Each sensory spot composed of one central pore, one long cilium, and numerous micropapillae (Fig. 6C). Type-1 glandular cell outlets, comprising numerous small pores, present in middorsal and lateroventral position (Figs 1A, B, 4C, 6A, B, E). Cuticular hairs arising from perforation sites covering almost entirely this and following nine segments (Figs 1A–D, 4B–D, 6A, C–F, 7A–C, E, 8A–D). Posterior part of this segment with primary pectinate fringe, but spinose processes quite small and visible only in SEM observation (Figs 4B, C, 6A, E).

Segment 2 with complete cuticular ring as segment 1 (Fig. 1A, B). Lateroventral tubes present (Figs 1A, 4B, 6A, E, 7A). Sensory spots present as one pair in middorsal, two pairs in laterodorsal and one pair in ventromedial position (Figs 1A, B, 4B, C, 6A, E). Each sensory spot of this and following segments consisting of one central pore and fewer micropapillae than those on segment 1 (Fig. 6D). Type-1 glandular cell outlet present in middorsal and ventromedial position (Figs 1A, B, 4B, C). Primary pectinate fringe on this and following seven segments with long spinose processes (Figs 1A, B, 4B, 6A, E). Spinose processes longest in midlateral to ventrolateral area.

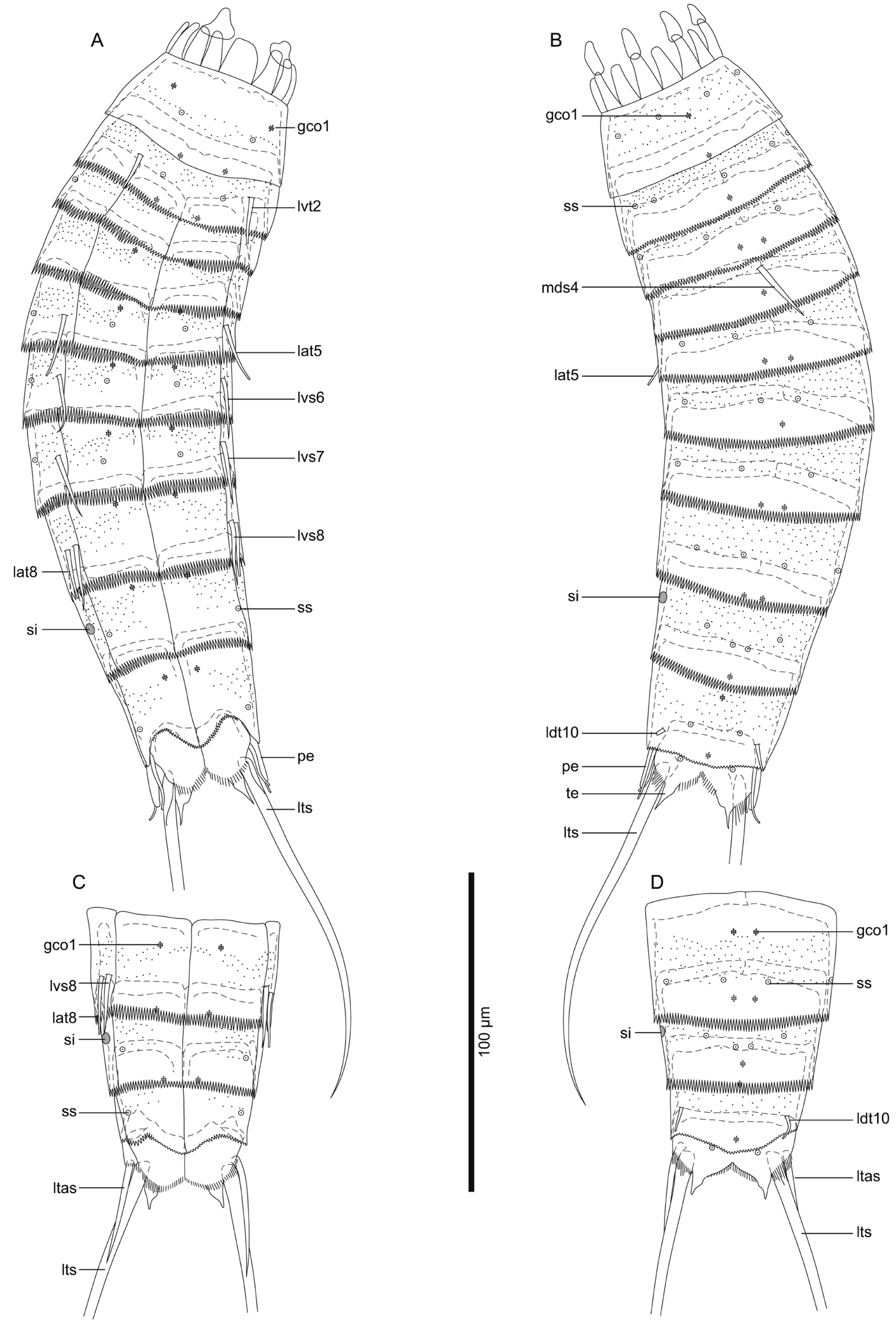


Fig. 1. *Echinoderes antalyaensis* sp. nov., camera lucida drawings. A, B, Holotype, male (ZMB 11673), entire animal, ventral and dorsal view of segments 1–11, respectively; C, D, paratype, female (ZMB 11674), segments 8–11, ventral and dorsal view, respectively. Abbreviations: gco1, type-1 glandular cell outlet; lat, lateral accessory tube; ldt, laterodorsal tube; ltas, lateral terminal accessory spine; lts, lateral terminal spine; lvs, lateroventral acicular spine; lvt, lateroventral tube; mds, middorsal acicular spine; pe, penile spine; si, sieve plate; ss, sensory spot; te, tergal extension. Digits after abbreviations, except for gco1, indicate the corresponding segment number.

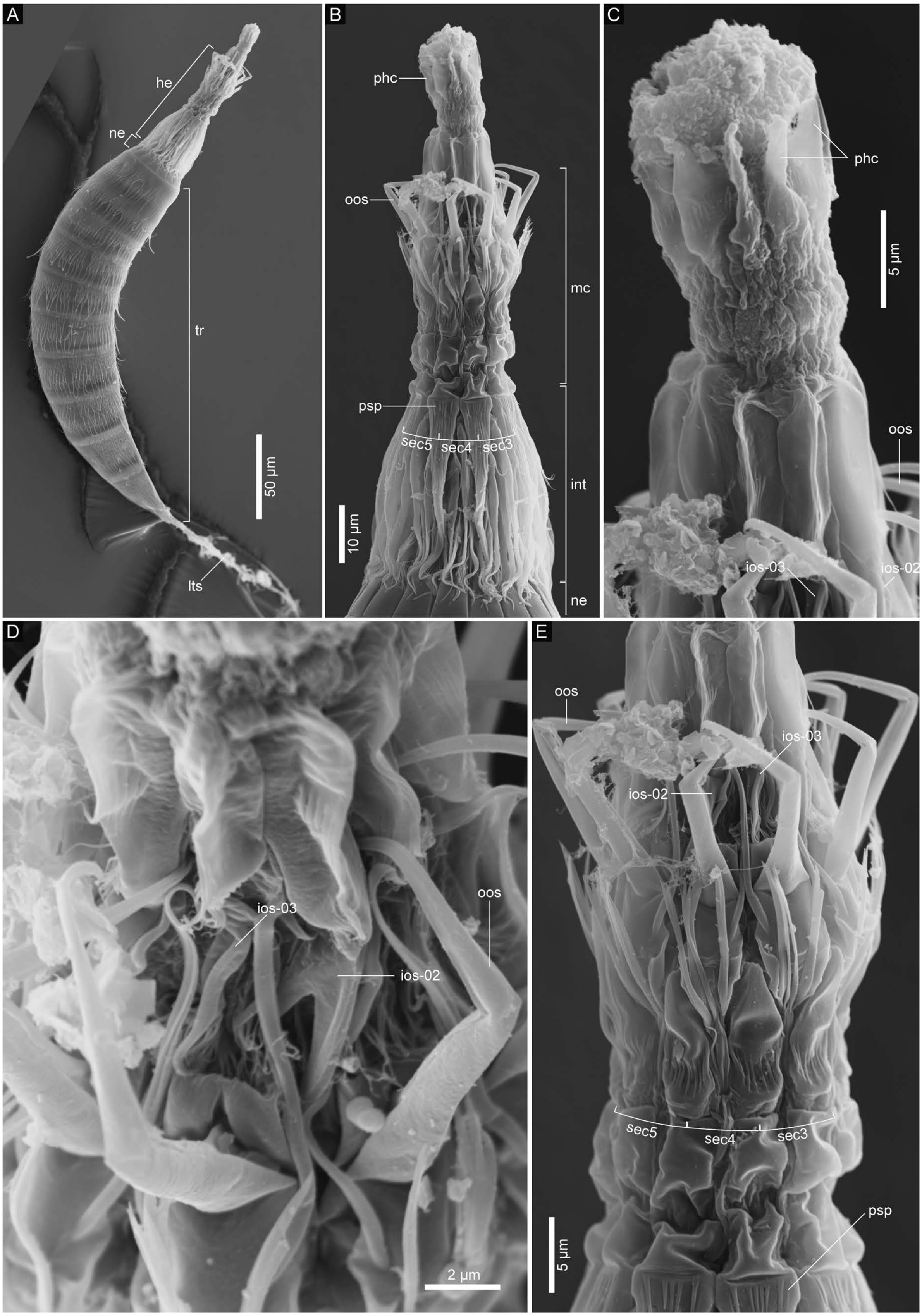


Fig. 2. *Echinoderes antalyaensis* sp. nov., a male (ZMB 11678), scanning electron micrographs. A, entire animal, lateral view (right side); B, head, lateral view (right side); C, close-up of inner oral styles, lateral view (right side); D, close-up of inner and outer oral styles, lateroventral view (right side); E, close-up of mouth cone, lateral view (right side). Abbreviations: he, head; int, introvert; ios, inner oral style; mc, mouth cone; ne, neck; oos, outer oral style; phc, pharynx crown; psp, primary spinoscalid; sec, sector; tr, trunk. Digits after abbreviations indicate the corresponding ring or sector number.

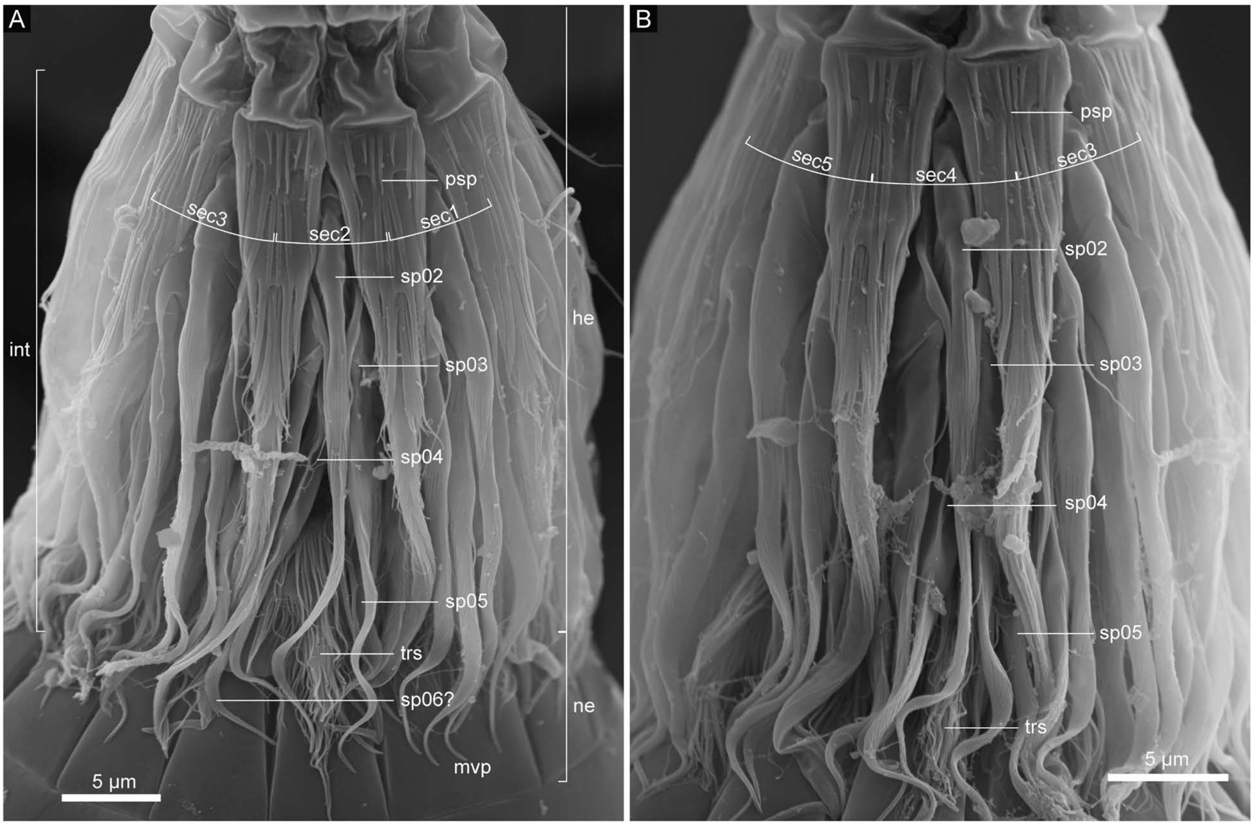


Fig. 3. *Echinoderes antalyaensis* sp. nov., a male (ZMB 11678), scanning electron micrographs. A, close-up of introvert, lateroventral view (right side); B, close-up of introvert, lateral view (right side). Abbreviations: he, head; int, introvert; mvp, midventral placid; ne, neck; psp, primary spinoscalid; sec, sector; sp, spinoscalid; trs, trichoscalid. Digits after abbreviations indicate the corresponding ring or sector number.

Segment 3 and following eight segments consisting of one tergal and two sternal plates (Fig. 1A, B). Sensory spots present in subdorsal and midlateral position (Figs 1A, B, 6A, E). Type-1 glandular cell outlets situated in middorsal and ventromedial position (Figs 1A, B, 4C).

Segment 4 with middorsal acicular spine (Figs 1B, 4C, 6F). Type-1 glandular cell outlets present in paradorsal and ventromedial position (Figs 1A, B, 4C).

Segment 5 with lateral accessory tubes (Figs 1A, 4B, D, 6F, 7A). Sensory spots in subdorsal, midlateral, and ventromedial position (Figs 1A, B, 6F, 7A). Type-1 glandular cell outlets in middorsal and ventromedial position (Figs 1A, B, 4C).

Segment 6 with lateroventral acicular spines (Figs 1A, 4D, 6F, 7A). Sensory spots present in paradorsal, midlateral, and ventromedial position (Figs 1A, B, 6F, 7A). Type-1 glandular cell outlets present paradorsally and ventromedially (Figs 1A, B, 4C).

Segment 7 with lateroventral acicular spines (Figs 1A, 4D, 7B, 8A, B). Sensory spots present in subdorsal, midlateral, and ventromedial position (Figs 1A, B, 7B). Type-1 glandular cell outlets present middorsally and ventromedially (Fig. 1A, B).

Segment 8 with lateral accessory tubes and lateroventral acicular spines (Figs 1A, C, 4D, 7B–D, 8A, B). Sensory spots present in paradorsal and laterodorsal position, but laterodorsal ones absent only in one out of six observed specimens (Figs 1B, D, 7B). Type-1 glandular cell outlets present paradorsally and ventromedially (Figs 1A, B, 8B).

Segment 9 without any spine and tube. Paradorsal, subdorsal, and ventrolateral sensory spots present (Figs 1A–D, 7C, 8A, B). Type-1 glandular cell outlets present in paradorsal and ventromedial position (Fig. 1A–D). Small sieve plates present in sublateral position (Fig. 1A–D).

Segment 10 with laterodorsal tubes (Figs 1B, D, 7E). Length of laterodorsal tubes in males slightly longer than those in females. Subdorsal and ventrolateral sensory spots present (Figs 1A–D, 7C, E, 8D). Two middorsal type-1 glandular cell outlets aligned in tandem (Fig. 1B, D). Additional pair of type-1 glandular cell outlets present in ventromedial position (Fig. 1A, C). Spinose processes of primary pectinate fringe thinner and shorter than those on preceding segment (Fig. 1A–D).

Segment 11 with lateral terminal spines (Figs 1A–D, 2A, 4A, 7E, 8C, D). Three pairs of penile spines present in males (Figs 1A, B, 7E, 8C). Dorsal and ventral penile spines long and tube-like, whereas middle ones stout and triangular-shaped. One pair of lateral terminal accessory spines present in females (Figs 1C, D, 8D). Subdorsal sensory spots present (Fig. 1B, D). Type-1 glandular cell outlet present middorsally (Fig. 1B, D). Posterior edge of tergal plate protruding subdorsally, forming pointed tergal extensions (Figs 1B, D, 8E, D). Posterior edges of sternal plates rounded with thin spinose processes (Fig. 1A, C).

Etymology. The specific epithet is an adjective referring to the type locality of the new species.

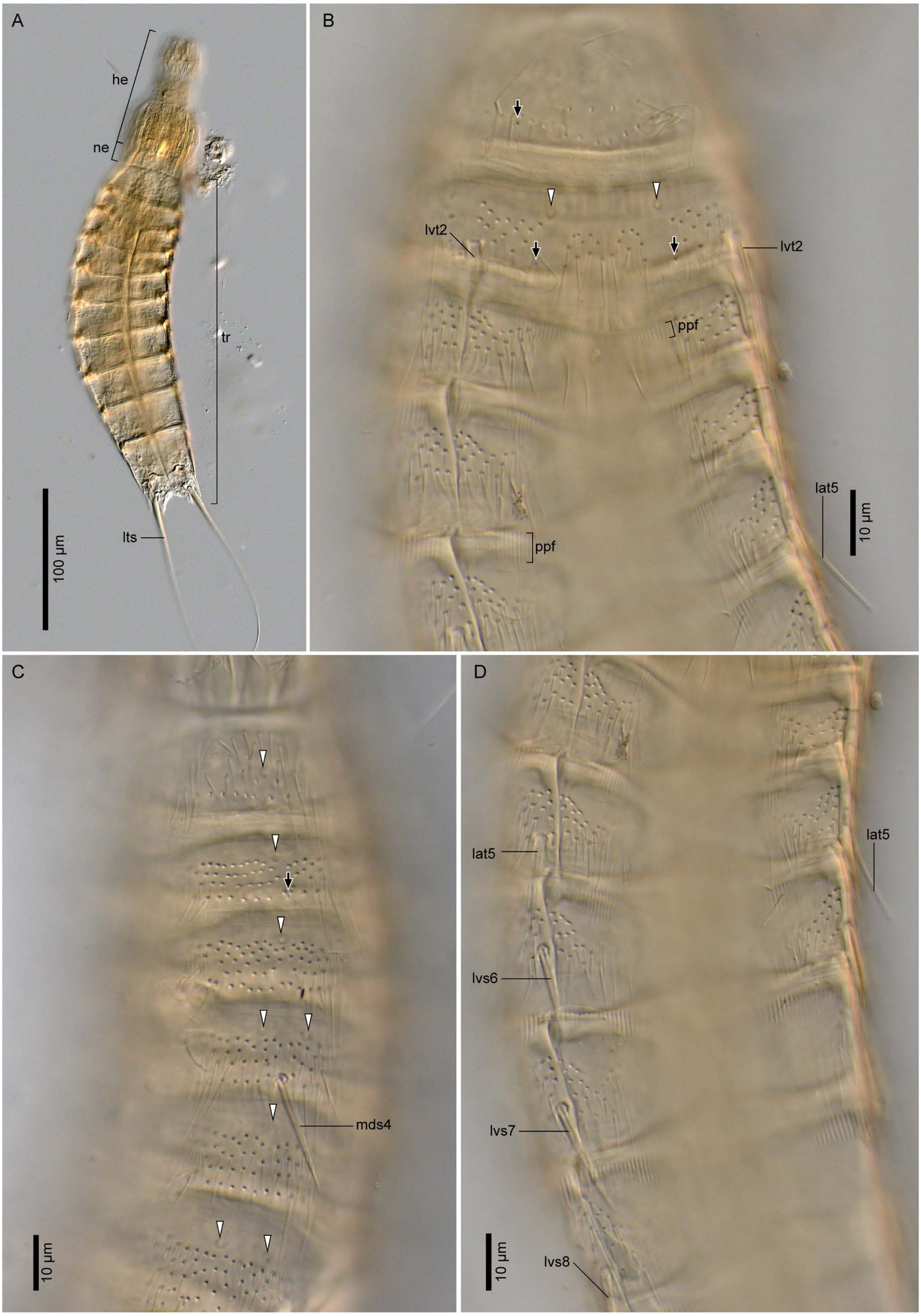


Fig. 4. *Echinoderes antalyaensis* sp. nov., Nomarski interference contrast photomicrographs of the holotypic male (ZMB 11673). A, entire animal, ventral view; B, segments 1–5, ventral view; C, neck and segments 1–6, dorsal view; D, segments 4–8, ventral view. Black arrows and white arrowheads indicate sensory spots and type-1 glandular cell outlets, respectively. Abbreviations: he, head; lat, lateral accessory tube; lts, lateral terminal spine; lvs, lateroventral acicular spine; lvt, lateroventral tube; mds, middorsal acicular spine; ne, neck; ppf, primary pectinate fringe; tr, trunk. Digits after abbreviations indicate the corresponding segment number.

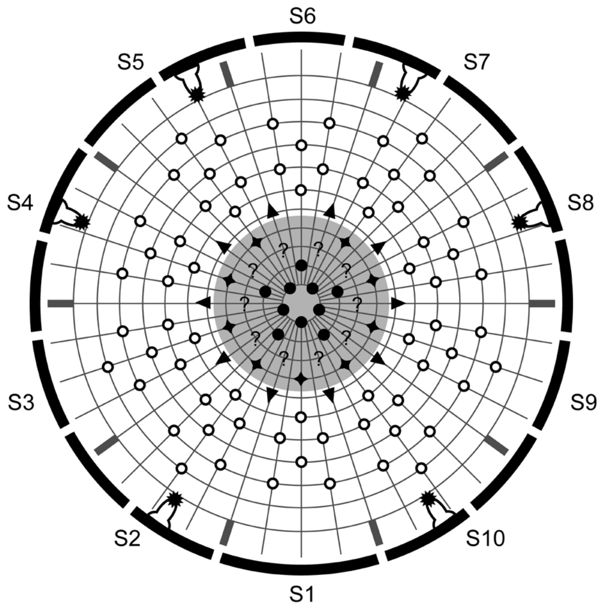
Table 1. Measurements for adult *Echinoderes antalyaensis* sp. nov. (in micrometers). Columns N and SD indicate sample size and standard deviation, respectively. Abbreviations: (ac), acicular spine; (f), measurements for females; la, length of lateral accessory tube; ld, length of laterodorsal tube; ltas, length of lateral terminal accessory spine; lts, length of lateral terminal spine; lv, length of lateroventral acicular spine or tube; (m), measurements for males; md, length of middorsal acicular spine; msw, maximum sternal width; s, segment length; sw, standard width; tl, trunk length; (tu) tube. Digits after abbreviations indicate corresponding segment.

Character	N	Holotypic male	Range	Mean	SD
tl	5	250	231–277	253.8	16.92
msw8	5	52	51–53	52.0	0.69
msw/tl	5	20.9%	19.1–22.2%	20.6	1.17
sw10	5	42	42–46	44.4	1.65
sw/tl	5	16.6%	16.2–19.0%	17.5	1.15
s1	5	32	29–32	31.1	1.24
s2	5	31	29–31	30.4	0.96
s3	5	23	22–25	23.5	1.28
s4	5	25	24–26	24.9	0.89
s5	5	26	25–27	25.7	0.70
s6	5	28	27–33	28.7	2.36
s7	5	32	30–35	31.7	2.11
s8	5	35	32–38	35.3	2.16
s9	5	35	35–40	36.3	2.28
s10	5	39	34–43	39.6	3.52
s11	5	27	26–31	28.7	2.24
md4 (ac)	4	22	19–22	20.7	1.16
lv2 (tu)	5	14	14–18	16.3	1.65
la5 (tu)	5	18	16–19	17.5	0.92
lv6 (ac)	5	20	19–21	20.2	0.62
lv7 (ac)	5	22	20–23	21.5	1.07
la8 (tu)	5	21	20–22	21.1	1.16
lv8 (ac)	5	18	17–19	17.9	0.53
ld10 (tu)	5	18	11–18	14.3	2.63
ld10 (tu) (m)	3	18	15–18	16.1	1.34
ld10 (tu) (f)	2	n.a.	11–13	11.7	1.15
lts	4	160	160–176	168.7	7.12
ltas	2	n.a.	32–37	34.3	3.27
lts/tl	4	63.8%	62.1–72.2%	66.3	4.45
ltas/tl	2	n.a.	13.8–14.7%	14.3	0.66

Table 2. Summary of locations of cuticular structures and spines in *Echinoderes antalyaensis* sp. nov. Underlined character found in 5 out of 6 specimens. Abbreviations: ac, acicular spine; (f), female condition of sexually dimorphic character; gco1, type 1 glandular cell outlet; LA, lateral accessory; LD, laterodorsal; ltas, lateral terminal accessory spine; lts, lateral terminal spine; LV, lateroventral; (m), male condition of sexually dimorphic character; MD, middorsal; ML, midlateral; pe, penile spine; PD, paradorsal; SD, subdorsal; si, sieve plate; SL, sublateral; ss, sensory spot; tu, tube; VL, ventrolateral; VM, ventromedial.

Position segment	MD	PD	SD	LD	ML	SL	LA	LV	VL	VM
1	gco1		ss	ss				gco1	ss	
2	gco1, ss			ss, ss				tu		gco1, ss
3	gco1		ss		ss					gco1
4	ac	gco1								gco1
5	gco1		ss		ss		tu			gco1, ss
6		gco1, ss			ss			ac		gco1, ss
7	gco1		ss		ss			ac		gco1, ss
8		gco1, ss		ss			tu	ac		gco1
9		gco1, ss	ss			si			ss	gco1
10	gco1, gco1		ss	tu					ss	gco1
11	gco1		ss				pe×3 (m), ltas (f)	lts		

Remarks. *Echinoderes antalyaensis* sp. nov. can easily be distinguished from other congeners by its unique spine/tube pattern: with middorsal acicular spine on segment 4, laterodorsal tubes on segment 10, lateral accessory tubes on segments 5 and 8, lateroventral tube on segment 2, and lateroventral acicular spines on segments 6–8. The new species



Scalid and style arrangement

Ring/Section		1	2	3	4	5	6	7	8	9	10	Total
-03 inner oral styles	●	1	0	1	0	1	0	1	0	1	0	5
-02 inner oral styles	●	0	1	0	1	0	1	0	1	0	1	5
-01 inner oral styles	?	?	?	?	?	?	?	?	?	?	?	?
00 outer oral styles	✦	1	1	1	1	1	0	1	1	1	1	9
01 primary spinoscalids	▼	1	1	1	1	1	1	1	1	1	1	10
02 spinoscalids	○	1	1	1	1	1	1	1	1	1	1	10
03 spinoscalids	○	2	2	2	2	2	2	2	2	2	2	20
04 spinoscalids	○	1	1	1	1	1	1	1	1	1	1	10
05 spinoscalids	○	2	2	2	2	2	2	2	2	2	2	20
06 spinoscalids	○	0	1	1	0	1	0	1	0	1	1	6
07 trichoscalids	✸	0	1	0	1	1	0	1	1	0	1	6

Fig. 5. Polar-coordinate diagram of mouth cone, introvert, and placids in *Echinoderes antalyaensis* sp. nov. Grey area and heavy line arcs show mouth cone and placids, respectively. The table lists the arrangement of styles and scalids by sector.

is the only species with this spine/tube pattern within *Echinoderes*.

The combination of the presence of middorsal acicular spine only on segment 4 and absence of any spines on segment 9 is a relatively rare character for the genus, which has been found only in nine species: *Echinoderes ajax* Sørensen, 2014, *Echinoderes cantabricus* Pardos *et al.*, 1998, *Echinoderes maxwelli* (Omer-Cooper 1957), *E. multiporus*, *Echinoderes ohtsukai* Yamasaki and Kajihara, 2012, *Echinoderes regina* Yamasaki, 2016, *E. rex*, *Echinoderes serratulus* Yamasaki, 2016, and *Echinoderes teretis* Brown, 1999 in Adrianov and Malakhov (1999) (Omer-Cooper 1957; Brown 1985; Pardos *et al.* 1998; Lundbye *et al.* 2011; Yamasaki and Kajihara 2012; Sørensen 2014; Herranz and Leander 2016; Yamasaki 2016; Yamasaki *et al.* 2018a). Of these nine species, the species belonging to the so called "*E. coulli* species group" (Sørensen 2014; Yamasaki 2016), *i.e.*, *E. maxwelli*, *E. ohtsukai*, *E. regina*, *E. rex*, *E. serratulus*, and *E. teretis*, are apparently different from *E. antalyaensis* sp. nov. in having a conspicuously large sieve plate on segment 9 and in lacking lateroventral tubes on segment 2 as well as lateroventral acicular spines on segment 8. *Echinoderes antalyaensis* sp. nov. can be distinguished from them, except for *E. teretis*, in possessing a smaller body size (trunk lengths are *ca.* 350–370 μm in *E. maxwelli*, 315–410 μm in *E. ohtsukai*, 451–503 μm in *E. regina*, 482–528 μm in *E. rex*, and 321–359 μm in *E. serratulus* opposed to 207–264 μm in *E. teretis* and 231–277 μm in *E. antalyaensis*) (Brown 1985; Lundbye *et al.* 2011; Yamasaki and Kajihara 2012; Sørensen 2014; Herranz and Leander 2016; Yamasaki 2016. Note: although Omer-Cooper [1957] described that the trunk length of *E. maxwelli* was 600 μm, the reexamination of the holotypic and one paratypic specimens revealed their trunk lengths are actually *ca.* 350–370 μm [Dr Martin V. Sørensen pers. comm.]; we used the latter in this study).

Echinoderes antalyaensis sp. nov. differs from *E. ajax* and *E. cantabricus* in the number and position of tubes on segment 2. *Echinoderes antalyaensis* sp. nov. has only one pair of tubes in the lateroventral position on segment 2, whereas *E. ajax* and *E. cantabricus* possess four pairs on the segment (tubes present in subdorsal, laterodorsal, sublateral, and ventrolateral position in *E. ajax*, and in laterodorsal, midlateral, sublateral, and ventrolateral position in *E. cantabricus*) (Pardos *et al.* 1998; Sørensen 2014). In addition, *E. antalyaensis* sp. nov. can be distinguished from *E. cantabricus* in the presence of lateral accessory tubes on segment 8 and the absence of midlateral tubes on segment 1 (Pardos *et al.* 1998).

Echinoderes antalyaensis sp. nov. differs from *E. multiporus* in the presence of lateroventral tubes on segment 2, lateral accessory tubes on segments 5 and 8, lateroventral acicular spines on segment 8, and the absence of type-2 glandular cell outlets (Yamasaki *et al.* 2018a).

Discussion

Among the Echinoderidae, characters of the head, *e.g.*, the inner and outer oral styles, spinoscalids, and trichoscalids, have received less attention than the characters of the trunk, such as shape and position of spines and tubes and type-1/2 glandular cell outlets. One of the reasons is the necessity of specimens with their head protruded for observation of the head characters. Furthermore, observations of several specimens both with LM and SEM are desirable to detect the complete morphologies on fine head characters. These requirements make the observation of head characters more difficult than those of the trunk, and little information of head characters and especially of minute structures, *e.g.*, ornaments of outer oral styles, has been accumulated so far. Although head structures of few species of Echinoderidae have been observed in detail, the morphological comparison between the structures in *Echinoderes antalyaensis* sp. nov. and those in other echinoderid species suggests that the ornaments of the basal unit of the outer oral styles are potentially useful for taxonomic purposes as well as in the phylogenetic and morphological evolutional study (Fig. 9; Table 3).

Until now, detailed information of the ornaments of the basal unit of the outer oral styles is available for 35 echinoderid species: 28 out of 107 *Echinoderes* species including

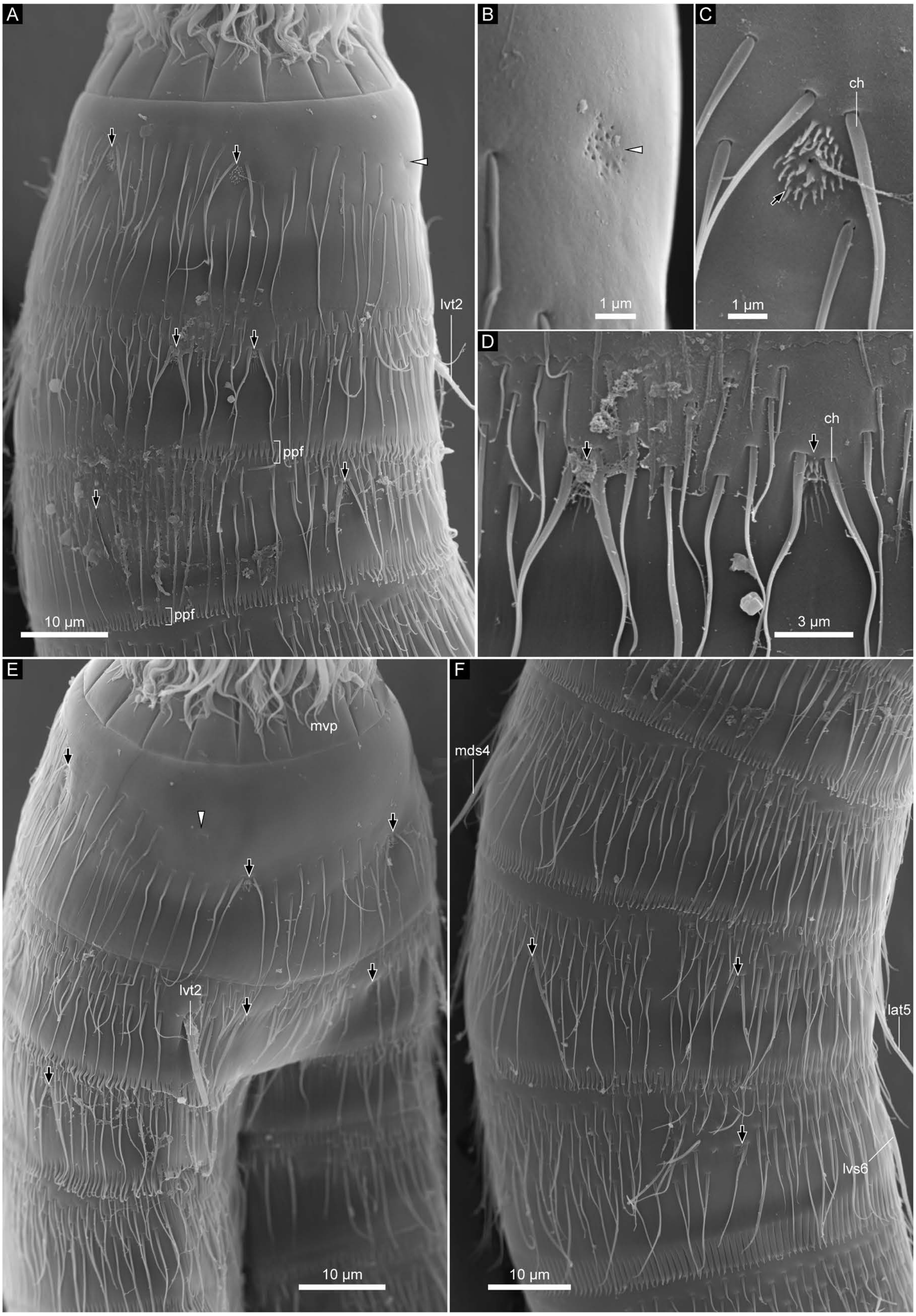


Fig. 6. *Echinoderes antalyaensis* sp. nov., a male (ZMB 11678), scanning electron micrographs. A, neck and segments 1–3, lateral view (right side); B, close-up of lateroventral type-1 glandular cell outlet on segment 1; C, close-up of laterodorsal sensory spot on segment 1; D, close-up of laterodorsal sensory spots on segment 2; E, neck and segments 1–4, lateroventral view (right side); F, segments 4–6, lateral view (right side). Black arrows and white arrowheads indicate sensory spots and type-1 glandular cell outlets, respectively. Abbreviations: ch, cuticular hair; lat, lateral accessory tube; lvs, lateroventral acicular spine; lvt, lateroventral tube; mds, middorsal acicular spine; mvp, midventral placid; ppf, primary pectinate fringe. Digits after abbreviations indicate the corresponding segment number.

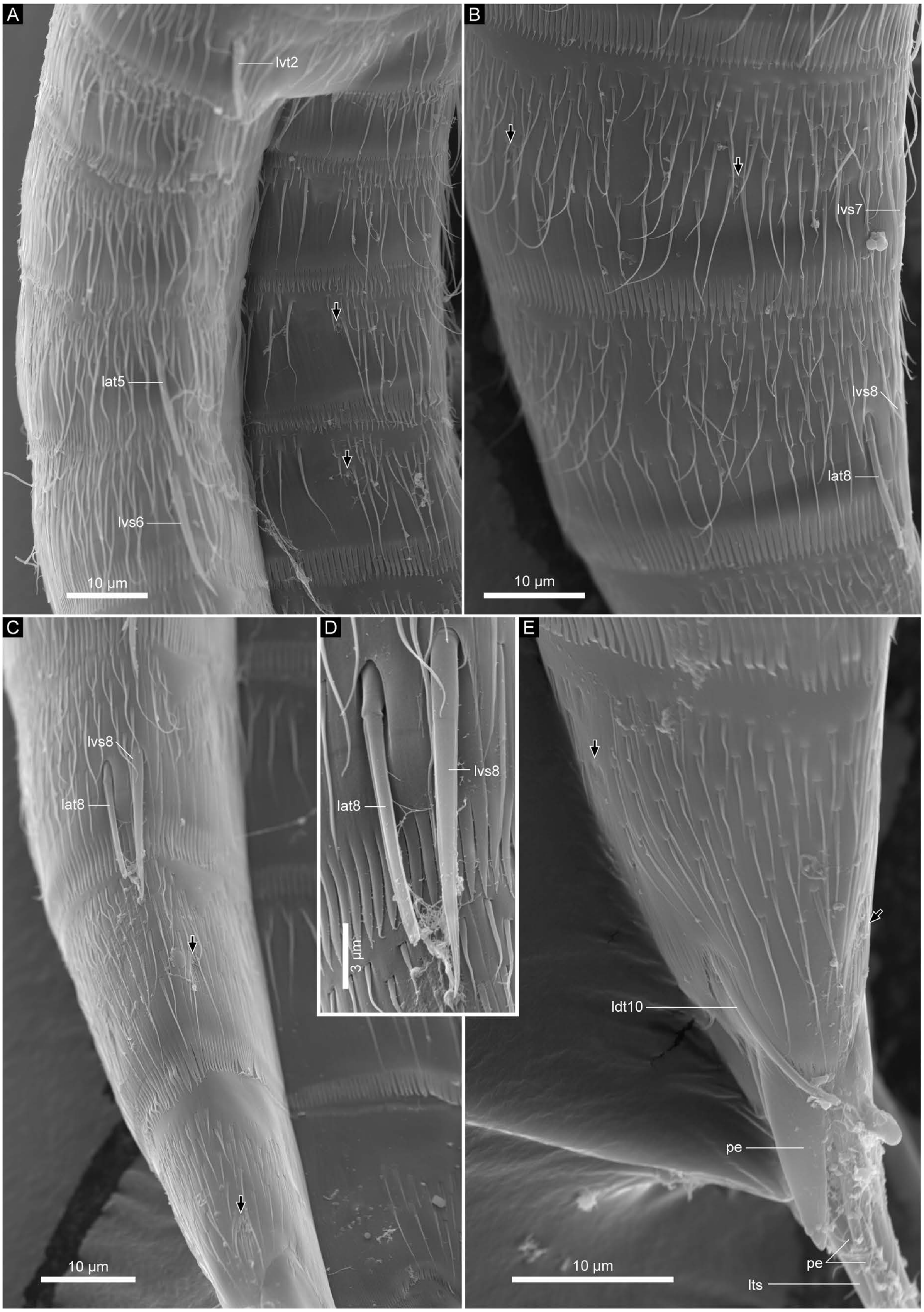


Fig. 7. *Echinoderes antalyaensis* sp. nov., a male (ZMB 11678), scanning electron micrographs. A, segments 2–6, lateroventral view (right side); B, segments 7 and 8, lateral view (right side); C, segments 8–10, lateroventral view (right side); D, close-up of lateral accessory tube and lateroventral acicular spine on segment 8; E, segments 10 and 11, lateral view (right side). Black arrows indicate sensory spots. Abbreviations: lat, lateral accessory tube; ldt, laterodorsal tube; lts, lateral terminal spine; lvs, lateroventral acicular spine; lvt, lateroventral tube; pe, penile spine. Digits after abbreviations indicate the corresponding segment number.

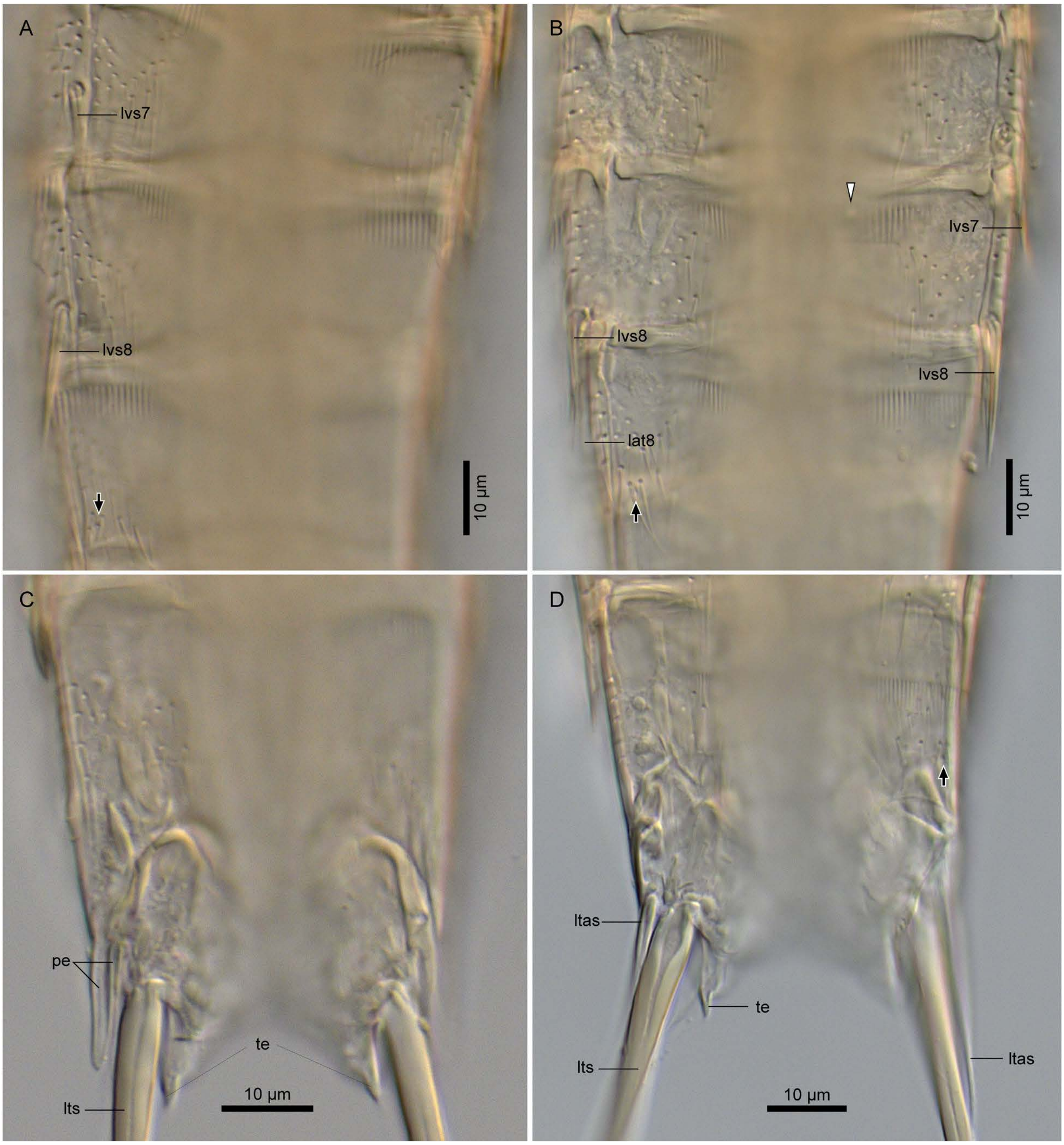


Fig. 8. *Echinoderes antalyaensis* sp. nov., Nomarski interference contrast photomicrographs of the holotypic male (ZMB 11673) (A, C) and paratypic female (ZMB 11674) (B, D). A, segments 7–9, ventral view; B, segments 7–9, ventral view; C, segments 10 and 11, ventral view; D, segments 10 and 11, ventral view. Black arrows and white arrowheads indicate sensory spots and type-1 glandular cell outlets, respectively. Abbreviations: lat, lateral accessory tube; ltas, lateral terminal accessory spine; lts, lateral terminal spine; lvs, lateroventral acicular spine; pe, penile spine; te, tergal extension. Digits after abbreviations indicate the corresponding segment number.

E. antalyaensis sp. nov., one of four *Cephalorhyncha* species, three of six *Fissuroderes* species, two of eight *Meristoderes* species, and one species of the monotypic genus *Polacanthoderes* (Fig. 9; Table 3). In most of these species regardless of genus, the ornaments of the basal unit of the outer oral styles is comprised of 2–6 central long spinose processes aligned in one row in posterior part and a pair of short lateral spinose processes in anterior part. The posterior spinose processes are bifurcated at its tip in 15 out of 35 species for which information exists (Fig. 9; Table 3). The uncommon characters in the posterior spinose processes are found in *Echinoderes applicitus* Ostmann *et al.*, 2012 with several long spinose processes aligning in several rows, and in *Polacanthoderes martinezi* Sørensen, 2008 with long spinose processes arising from lateral sides (Sørensen 2008; Ostmann *et al.* 2012). The anterior spinose processes also differ considerably in some species: *Echinoderes antalyaensis* sp. nov. has a pair of very long lateral spinose processes which are similar in length to its outer oral styles; *E. microaperturus* has more than 10 short spinose processes which align horizon-

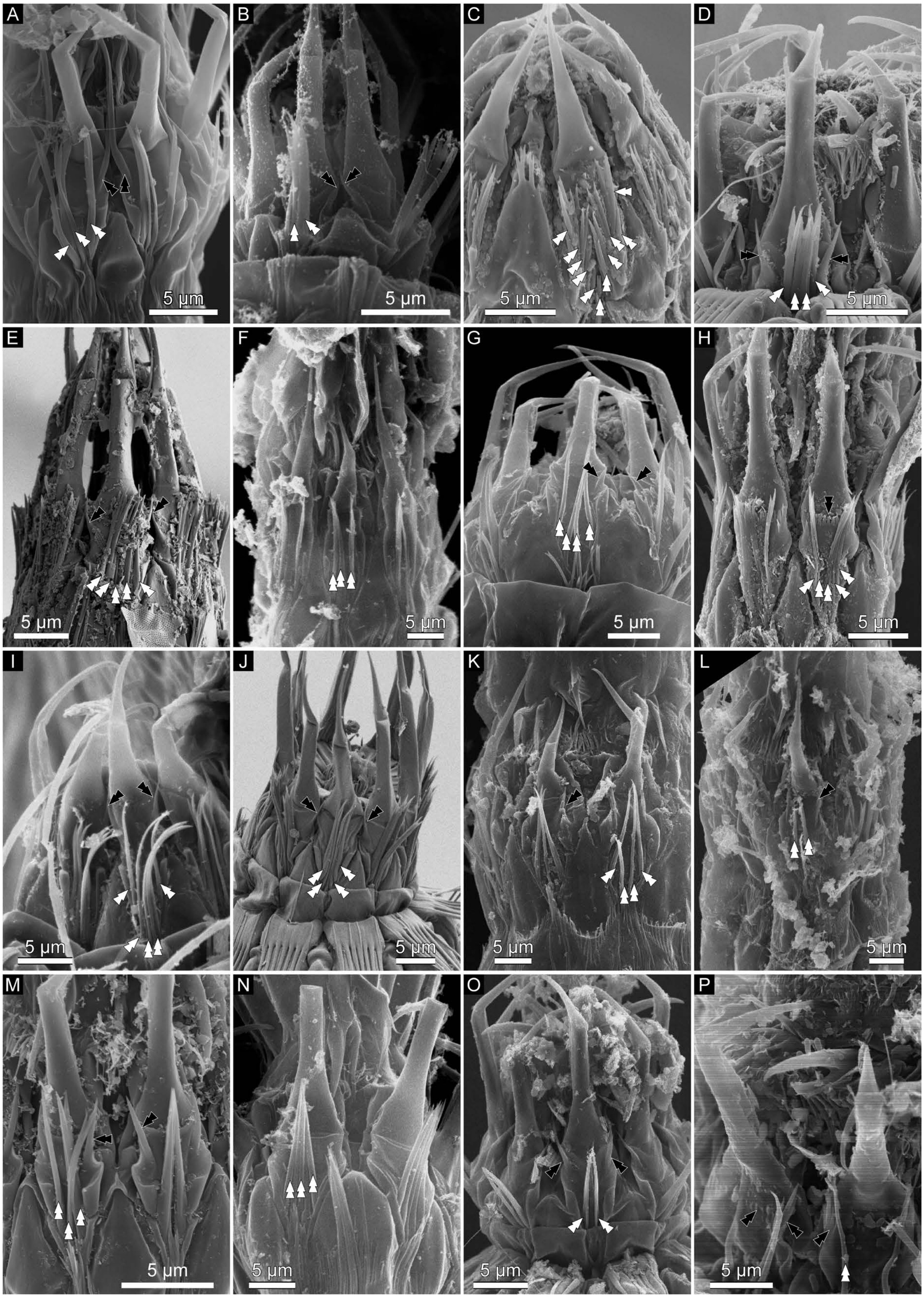


Fig. 9. Ornaments of outer oral styles in various echinoderid species. A, *E. antalyensis* sp. nov.; B, *E. apex*; C, *E. applicitus*; D, *E. cernunnos*; E, *E. hakaiensis*; F, *E. hwiizaa*; G, *E. komatsui*; H, *E. microaperturus*; I, *E. ohtsukai*; J, *E. pennaki*; K, *E. regina*; L, *E. serratulus*; M, *E. tchefouensis*; N, *C. asiatica*; O, *M. macracanthus*; P, *P. martinezi*. Black and white double-arrowheads indicate anterior and posterior spinose processes, respectively. Photographs C, D, H, and M, and photographs E, J, and O were taken and provided by Dr Martin V. Sørensen and Dr María Herranz, respectively.

Table 3. Comparison of the ornamental structures on outer oral styles within echinoderid species. Information is obtained from the description of the species and/or the SEM photographs in the referenced paper. Unique characters are marked in bold.

species	Ornament of the basal unit of outer oral styles		Reference
	posterior spinose processes	anterior spinose processes	
Echinoderes antalyaensis sp. nov.	3–4 bifurcated long spinose processes in central area	**one pair of very long lateral spinose processes**	Fig. 9A; This study
Echinoderes ajax	4 long spinose processes in central area	one pair of short lateral spinose processes	Sørensen (2014)
Echinoderes apex	3–4 bifurcated long spinose processes in central area	one pair of very short lateral spinose processes	Fig. 9B; Yamasaki *et al.* (2018b)
Echinoderes applicitus	**10> bifurcated long spinose processes aligning in several rows** in central area	absent	Fig. 9C; Ostmann *et al.* (2012)
Echinoderes astridae Sørensen, 2014	4 long spinose processes in central area	one pair of short lateral spinose processes	Sørensen (2014)
Echinoderes augustae Sørensen and Landers, 2014	3 bifurcated long spinose processes in central area	one pair of short lateral spinose processes	Sørensen and Landers (2014)
Echinoderes bookhouti Higgins, 1964	3 long spinose processes in central area	one pair of short lateral spinose processes	Sørensen *et al.* (2016)
Echinoderes capitatus (Zelinka, 1928),	4−6 long spinose processes in central area	one pair of short lateral spinose processes	Nebelsick (1993)
Echinoderes cernunnos Sørensen *et al.*, 2012	4 bifurcated long spinose processes in central area	one pair of short lateral spinose processes	Fig. 9D; Sørensen *et al.* (2012)
Echinoderes charlotteae	3 long spinose processes in central area	one pair of short lateral spinose processes	Sørensen *et al.* (2016)
Echinoderes gizoensis	4 (?) long spinose processes in central area	absent (?)	Thormar and Sørensen (2010)
Echinoderes hakaiensis Herranz *et al.*, 2018	6 bifurcated long spinose processes in central area	one pair of short lateral spinose processes	Fig. 9E; Herranz *et al.* (2018)
Echinoderes hwiizaa	2−3 bifurcated long spinose processes in central area	absent	Fig. 9F; Yamasaki and Fujimoto (2014)
Echinoderes joyceae Landers and Sørensen, 2016	3 long spinose processes in central area	one pair of short lateral spinose processes	Landers and Sørensen (2016)
Echinoderes kanni Thormar and Sørensen, 2010	2−4 long spinose processes in central area	one pair of short lateral spinose processes	Thormar and Sørensen (2010)
Echinoderes komatsui	2−4 bifurcated long spinose processes in central area	one pair of very short lateral spinose processes	Fig. 9G; Yamasaki and Fujimoto (2014)
Echinoderes kozloffi Higgins, 1977	3−4 long spinose processes in central area	n.a.	Herranz and Leander (2016)
Echinoderes lusitanicus Neves *et al.*, 2016	4 long spinose processes in central area	one pair of short lateral spinose processes	Neves *et al.* (2016)
Echinoderes marthae	5 long spinose processes in central area	absent	Sørensen (2014)
Echinoderes microaperturus Sørensen *et al.*, 2012	4–6 bifurcated long spinose processes in central area	**>10 spinose processes aligned horizontally in central to lateral area**	Fig. 9H; Sørensen *et al.* (2012)
Echinoderes ohtsukai	6 long spinose processes in central area	one pair of very short lateral spinose processes	Fig. 9I; Yamasaki and Kajihara (2012); Herranz and Leander (2016)
Echinoderes pennaki Higgins, 1960	4−5 bifurcated long spinose processes in central area	one pair of short lateral spinose processes	Fig. 9J; Herranz *et al.* (2018)
Echinoderes regina	3−5 long spinose processes in central area	one pair of short lateral spinose processes	Fig. 9K; Yamasaki (2016)
Echinoderes riceae Herranz *et al.*, 2014	5 long spinose processes in central area	one pair of short lateral spinose processes	Herranz *et al.* (2014)
Echinoderes romanoi Landers and Sørensen, 2016	2−3(?) long spinose processes in central area	one pair of short lateral spinose processes	Landers and Sørensen (2016)
Echinoderes serratulus	2−3 bifurcated long spinose processes in central area	one pair of short lateral spinose processes	Fig. 9L; Yamasaki (2016)
Echinoderes skipperae Sørensen and Landers, 2014	4−6 long spinose processes in central area	one pair of short lateral spinose processes	Sørensen and Landers (2014)
Echinoderes tchefouensis Lou, 1934	2–3 bifurcated long spinose processes in central area	one pair of short lateral spinose processes	Fig. 9M; Sørensen *et al.* (2012)
Cephalorhyncha asiatica	4-5 bifurcated long spinose processes in central area	absent	Fig. 9N; Yamasaki *et al.* (2012)
Fissuroderes higginsi Neuhaus, 2006 in Neuhaus and Blasche (2006)	*ca.* 6 short spinose processes (?)	n.a.	Neuhaus and Blasche (2006)
Fissuroderes rangi Neuhaus, 2006 in Neuhaus and Blasche (2006)	*ca.* 6 short spinose processes (?)	n.a.	Neuhaus and Blasche (2006)
Fissuroderes thermoi Neuhaus and Blasche, 2006	several short spinose processes (?)	n.a.	Neuhaus and Blasche (2006)
Meristoderes boylei Herranz and Pardos, 2013	2–3 (?) bifurcated long spinose processes in central area	one pair of short lateral spinose processes	Herranz and Pardos (2013)
Meristoderes macracanthus Herranz *et al.*, 2012	2 bifurcated long spinose processes in central area	one pair of short lateral spinose processes	Fig. 9O; Herranz *et al.* (2012)
Polacanthoderes martinezi	**2–3 long spinose processes in lateral sides**	**horizontally aligned minutes spinose processes flanked by one pair of short and multifurcated spinose processes**	Fig. 9P; Sørensen (2008)

tally in central to lateral area; *P. martinezi* has a horizontal line of several minutes spinose processes which is flanked by one pair of multifurcated spinose processes; the anterior lateral spinose processes are very short and inconspicuous in *Echinoderes apex* Yamasaki *et al.*, 2018, *Echinoderes komatsui* Yamasaki and Fujimoto, 2014, and *E. ohtsukai*, or even absent in *E. applicitus*, *Echinoderes gizoensis* Thormar and Sørensen, 2010, *Echinoderes hwiizaa* Yamasaki and Fujimoto, 2014, *Echinoderes marthae* Sørensen, 2014, *Cephalorhyncha asiatica* (Adrianov 1989) (see Sørensen 2008, 2014; Thormar and Sørensen 2010; Ostmann *et al.* 2012; Sørensen *et al.* 2012; Yamasaki *et al.* 2012; Yamasaki and Fujimoto 2014; Herranz and Leander 2016).

Although clear differences are present in the ornaments on the head characters among species of Echinoderidae, there is not enough information to compare the characters exhaustively within the echinoderid genera and species at the moment. The character of the outer oral styles of *E. antalyaensis* sp. nov. is not mentioned as a species-diagnostic character in this study, although the character seems to be unique within the genus *Echinoderes* as well as the family Echinoderidae. In addition to the ornaments of outer oral styles, the ornaments of primary spinoscalids show high morphological variety among species (Dr María Herranz pers. comm.) and can be also a potential taxonomic character. In order to make them available for a comparison of taxonomic characters, detailed observations of the fine structures on the head is recommended in future studies dealing with the observation of the already described species and/or the description of new species.

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