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North West Pacific deep-sea barnacles (Cirripedia, Thoracica) collected by the TAIWAN expeditions, with descriptions of two new species

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Abstract

Taiwan is a large island in north western Pacific waters with the sea floor connecting to two major deep-sea basins, the eastern waters facing the Pacific Ocean (to 4000 m depth) and linking to the Philippine Basin, whilst south western waters are associated with the South China Sea Basin (up to 1000 m). Previously, the biodiversity of Taiwanese deep-sea barnacles had not been studied extensively, due to a lack of deep-sea expeditions and sampling. Recently, several TAIWAN deep-sea cruises investigated the biodiversity of the deep-sea fauna of Taiwan and sampling was conducted to depths of 4000 m. The present study reports on the biodiversity of the deep-sea barnacles of Taiwan, a total of 18 species. One species was previously recorded from Taiwanese waters and 17 are new records, including two new species belong to the genera *Litoscalpellum* and *Altiverruca*.

Key words:

Introduction

Taiwan is a large island located in the north western Pacific, supporting a high diversity of shallow water and deep-sea habitats. The waters to the south west of Taiwan connect to the South China Sea Basin (depth to 1000 m). Eastern coasts face the Pacific Ocean, linking to the West Philippine Basin (to 4000 m) and north eastern waters open to the Okinawa Trough (Wang, 1991). The biodiversity of the deep-sea barnacles of Taiwan have received scant attention and few deep-sea species have been reported. Previous records in Taiwan were often focused on intertidal and shallow water species (e.g. Hiro, 1939a, b). In recent years, with support from the National Science Council, Taiwan, several cruises were conducted to survey the deep-sea fauna of Taiwanese waters. Sampling by the TAIWAN expeditions was conducted using benthic French beam trawls in depths to 4000 m (Tsai et al., 2009). The present study reports on 18 deep-sea species collected by the recent TAIWAN expeditions plus collections from deep-sea fishing markets. One species had been previously recorded from Taiwanese waters, two were new species and 15 new records for Taiwanese waters.

Material and methods

The 4m French beam trawl used in the TAIWAN expeditions is abbreviated as (CP), indicated before the station number. Specimens are deposited in the National Museum of Natural Science, Taichung, Taiwan (NMNS) and the Research Museum of Biodiversity Research Center, Academia Sinica (ASIZCR), and research collections in the coastal ecology laboratory, Academia Sinica (CEL). For stalked barnacles, size (in mm) was measured as capitular length (CL), capitular width (CW) and peduncular length (PL) and for sessilian barnacles as basal rostro-carinal diameter (BD).

Taxonomy

Order Lepadiformes Buckeridge & Newman, 2006

Suborder Lepadomorpha Pilsbry, 1916

Family Poecilasmatidae Annandale, 1909

Genus *Glyptelasma* Pilsbry, 1907

Glyptelasma gigas (Annandale, 1916)

Figures 1A, 3

Poecilasma gigas Annandale, 1916: 299, pl. 4 fig. 4, pl. 5 figs 10–14, pl. 6 figs 7, 8.
Megalasma (*Glyptelasma*) *gigas*. — Calman, 1919: 364. — Nilsson-Cantell, 1928: 20. — Zevina, 1982: 85, fig. 75.
Glyptelasma gigas. — Broch, 1931: 32, fig. 12.

Material examined. NMNS 005087-00078, 8 specimens, Stn. CP132 (22°20.98'N, 120°6.73'E, 21 Nov. 2001, depth: 690–700 m), CL 7.67–15.41 mm, CW 4.46–9.28 mm, PL 3.72–9.79 mm.

Diagnosis. Largest known species of *Glyptelasma*; peduncle long; carinal base laterally expanded; scutum with basal and occludent margins forming right angle.

Description. Capitulum large, 5 smooth, white, opaque plates, separated by narrow, chitinous inter-spaces (Fig. 1A); tergum quadrangular, all margins straight; scutum ovoid, occludent margin convex, basal and tergal margins straight, carinal margin strongly convex, basal and occludent margins forming right angle (Fig. 1A); carina bowed, basal laterally expanded (Fig. 1A). Peduncle long, yellow, surface concentrically wrinkled (Fig. 1A). Maxilla bilobed, setae in 2 main clusters (Fig. 3A); maxillule notched, 2 large, long, cuspidate setae above notch, short spines in notch, 10 cuspidate setae below notch, region below notch expanded outwards (Fig. 3B); mandible with 6 teeth excluding inferior angle, first tooth separated from remaining teeth, lower margin very short, smooth, inferior angle terminating in 1 sharp seta (Fig. 3C); mandibular palp narrow, elongated, setae on superior margin (Fig. 3D); labrum concave, without deep notch, cutting edge with dense, fine teeth (Fig. 3E, I). Cirrus I with rami subequal; outer ramus 10-segmented, inner ramus 8-segmented (Fig. 3F); cirrus II with outer ramus 14-segmented, inner ramus 15-segmented (Fig. 3G); caudal appendage short, 1-segmented, length < height of basal segment of pedicle of cirrus VI (Fig. 3H).

Distribution. Malaysia, South China Sea, Taiwan.

Remarks. This is a new record for Taiwanese waters.

Order Scalpelliformes Buckeridge & Newman, 2006

Family Calanticidae Zevina, 1978

Genus *Euscalpellum* Hoek, 1907

Euscalpellum rostratum (Darwin, 1851)

Figures 1B, 4

Scalpellum rostratum Darwin, 1851: 259, pl. 6 fig. 7.
Scalpellum (*Euscalpellum*) *rostratum*. — Hoek, 1907: 65, pl. 5 fig. 13. — Stubbings, 1936: 19 fig. 7.
Euscalpellum rostratum. — Pilsbry, 1908: 107, figs 1e–f. — Utinomi, 1968: 162, fig. 1. — Zevina, 1978: 1001. — Liu & Ren, 1985: 190, fig. 5, pl. 3 figs 1–2. — Liu & Ren, 2007: 214, fig. 90.
Scalpellum (*Smilium*) *rostratum*. — Annandale, 1914: 274.
Smilium rostratum. — Broch, 1931: 14. — Nilsson-Cantell, 1938: 24, fig. 1.

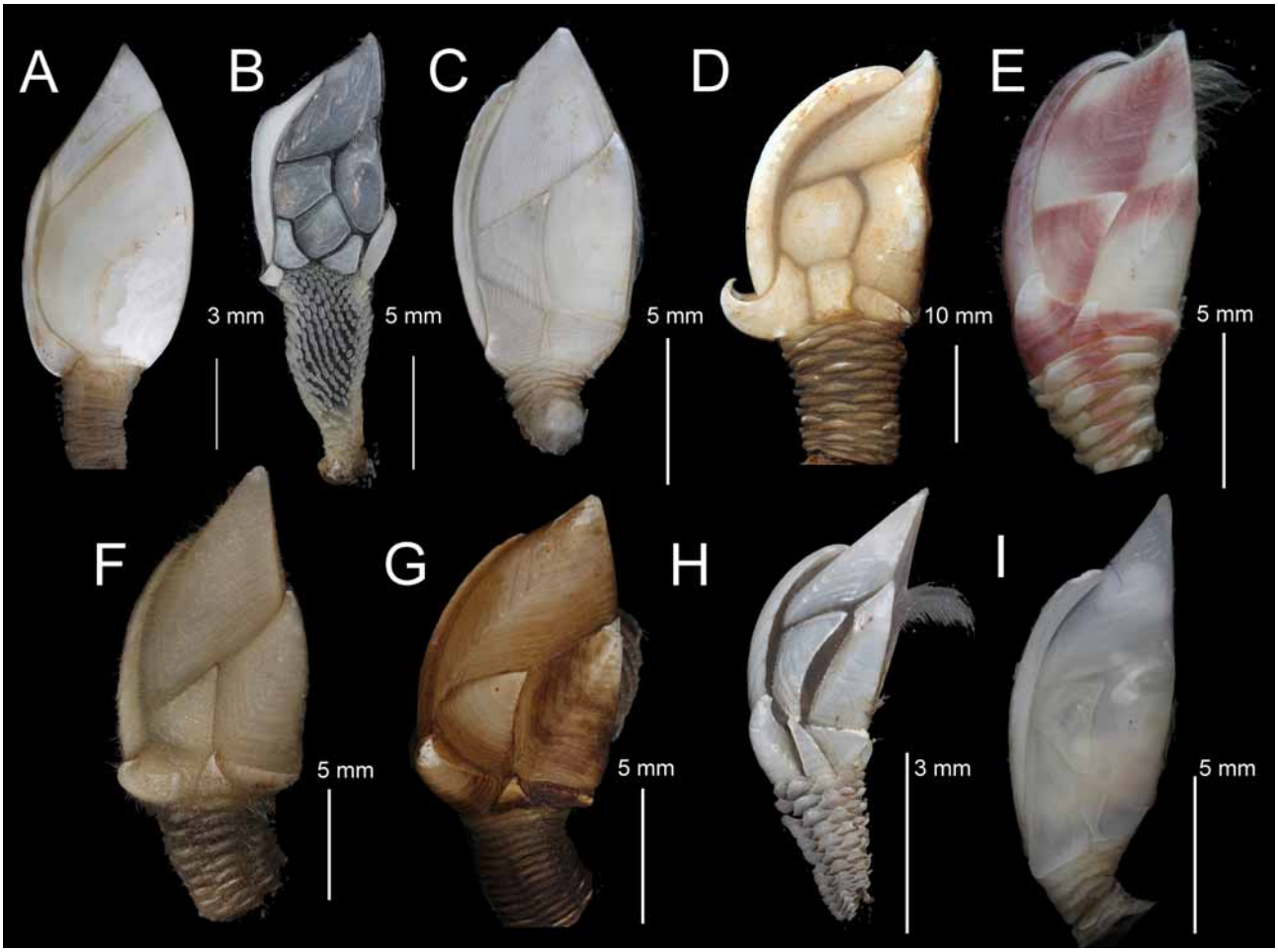

FIGURE 1. Taiwanese deep-sea barnacles (right side view). A. *Glyptelasma gigas*, B. *Euscalpellum rostratum*, C. *Arcoscalpellum truncatum*, D. *Tarasovium orientale*, E. *Trianguloscalpellum diota*, F. *Trianguloscalpellum hirsutum*, G. *Trianguloscalpellum regium*, H. *Trianguloscalpellum weltnerianum*, I. *Verum novazelandiae*.

Material examined. ASIZCR000225, 1 specimen, Stn. CP164 (22°15.57'N, 120°35.56'E, 25 May 2002, depth: 60–90 m), CL 9.76 mm, CW 6.44 mm, PL 7.6 mm.

Diagnosis. Capitulum higher than wide; 15 white plates; subcarina present; rostrum large, well developed; inframedian latus diamond-shaped; rostrolatus quadrangular, umbo apical.

Description. Capitulum higher than wide, 15 fully calcified, white plates; tergum truncated, quadrangular, wider than high, occludent and basal margins slightly convex, umbo apical (Fig. 1B); scutum irregularly-shaped, occludent margin almost straight, tergal, lateral and basal margins convex, umbo subapical; upper latus pentagonal, tergal margin longest, apex produced over scutal tergal angle, umbo apical (Fig. 1B); inframedian latus diamond-shaped, umbo apical (Fig. 1B); rostrolatus quadrangular, umbo apical; carinolatus quadrangular, umbo apical (Fig. 1B); rostrum well developed, large, diamond-shaped; carina strongly bowed, umbo apical, roof wide, laterally convex; subcarina quadrangular (Fig. 1B). Peduncle long, with dense, fine scales (Fig. 1B). Maxilla bilobed, setae distributed into 2 main clusters (Fig. 4A); maxillule cutting edge with small notch close to apical region, cutting edge not straight, basal region below notch slightly extended; 2 long setae above notch, > 6 setae below notch, > 10 large setae along extended basal region (Fig. 4B); mandible with 6 teeth, first separated from remainder, inferior angle ending in single sharp seta (Fig. 4C); mandibular palp elongated, setae on superior and inferior margins and distally (Fig. 4D); labrum with cutting edge concave, smooth, teeth absent. Cirrus I separated from remaining cirri, rami unequal, outer ramus longer, 12-segmented, inner ramus shorter, 8-segmented (Fig. 4F); cirri II–VI with rami sub-equal; cirrus II with outer ramus 16-segmented, inner ramus 14-segmented (Fig. 4G); caudal appendage short, 1-segmented, apex with dense, short setae, appendage length < height of basal segment of pedicle of cirrus VI (Fig. 4E).

Distribution. South China Sea, Taiwan, the Philippines, Malay Archipelago, Arabian Sea.
Remarks. This is a new record for Taiwanese waters.

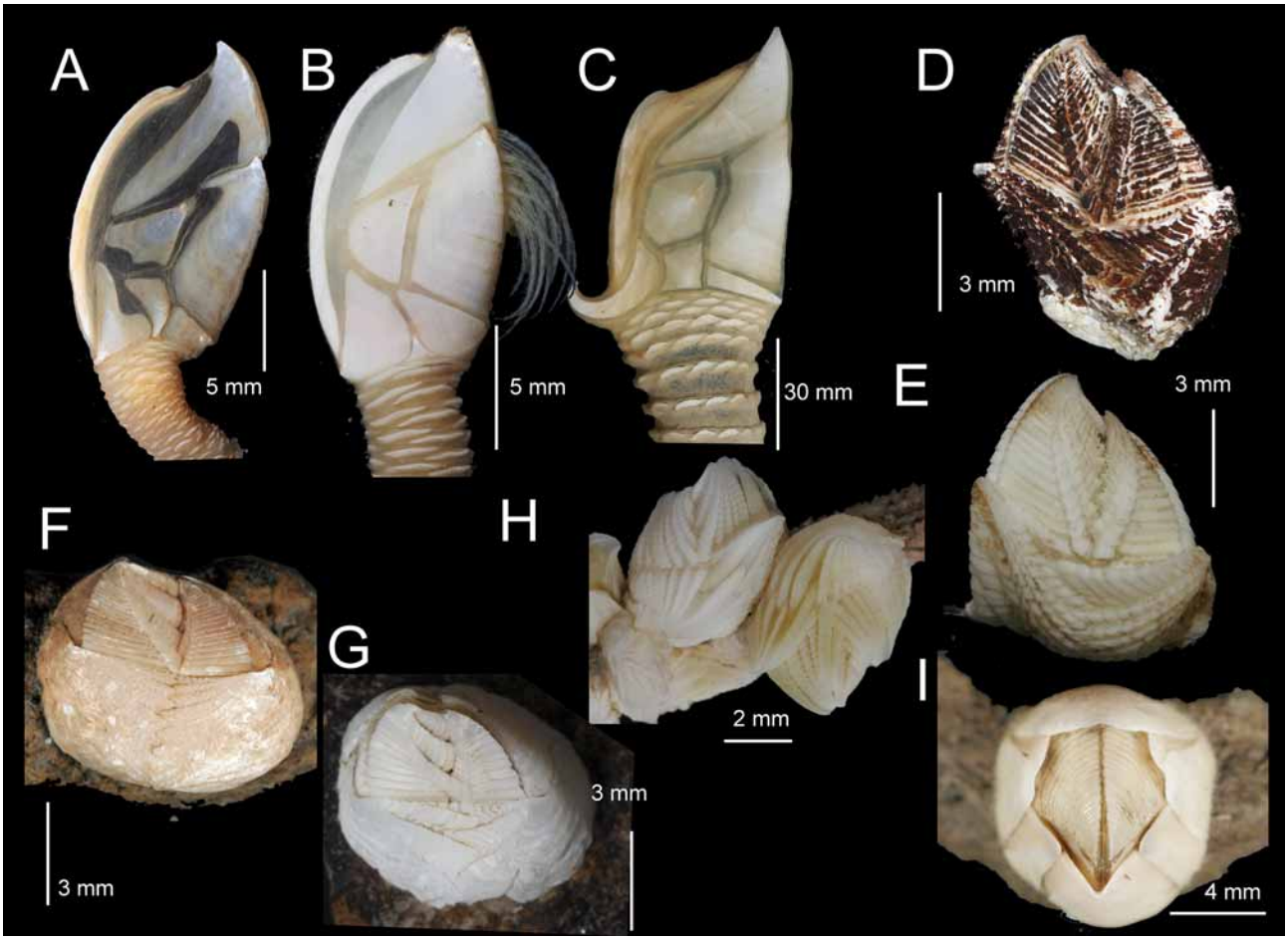

FIGURE 2. Taiwanese deep-sea barnacles (right side view on A–C, top view for D–I). A. *Annandaleum japonicum biramosum*, B. *Litoscalpellum spinosus* **sp. nov.**, C. *Scalpellum stearnsii*, D. *Altiverruca longimandible* **sp. nov.**, E. *Altiverruca navicula*, F. *Metaverruca defayeae*, G. *Metaverruca recta*, H. *Rostratoverruca krugeri*, I. *Hexelasma velutinum*.

Family Scalpellidae Pilsbry, 1916

Sub-family Arcoscalpellinae Zevina, 1978

Genus *Arcoscalpellum* Hoek, 1907

***Arcoscalpellum truncatum* (Hoek, 1883)**
Figures 1C, 5

Scalpellum truncatum Hoek, 1883: 92, pl. 6 fig. 13. — Zevina, 1973: 846.
Arcoscalpellum truncatum. — Zevina, 1981: 334, fig. 254.

Material examined. NMNS 005087-00073, 1 specimen, Stn. CP185 (22º0.54'N, 119º 27.94'E, 26 Aug. 2002, depth: 2334–2543 m), CL 12.94 mm, CW 7.39 mm, PL 4.06 mm; CEL-BB-46D, 1 specimen, Stn. CP375 (24º16.240'N, 122º11.720'E, 27 Aug. 2006, depth: 2216–2497 m), CL 18.17 mm, CW 9.29 mm, PL 4.39 mm.

Diagnosis. 14 fully calcified capitular plates, white, surfaces striated with radiating lines; tergum pentagonal, bluntly truncated; inframedian latus narrow, triangular, touching upper latus; carinolatus with umbo at basicarinal angle, located in middle of carinal margin; carina bowed, umbo apical.

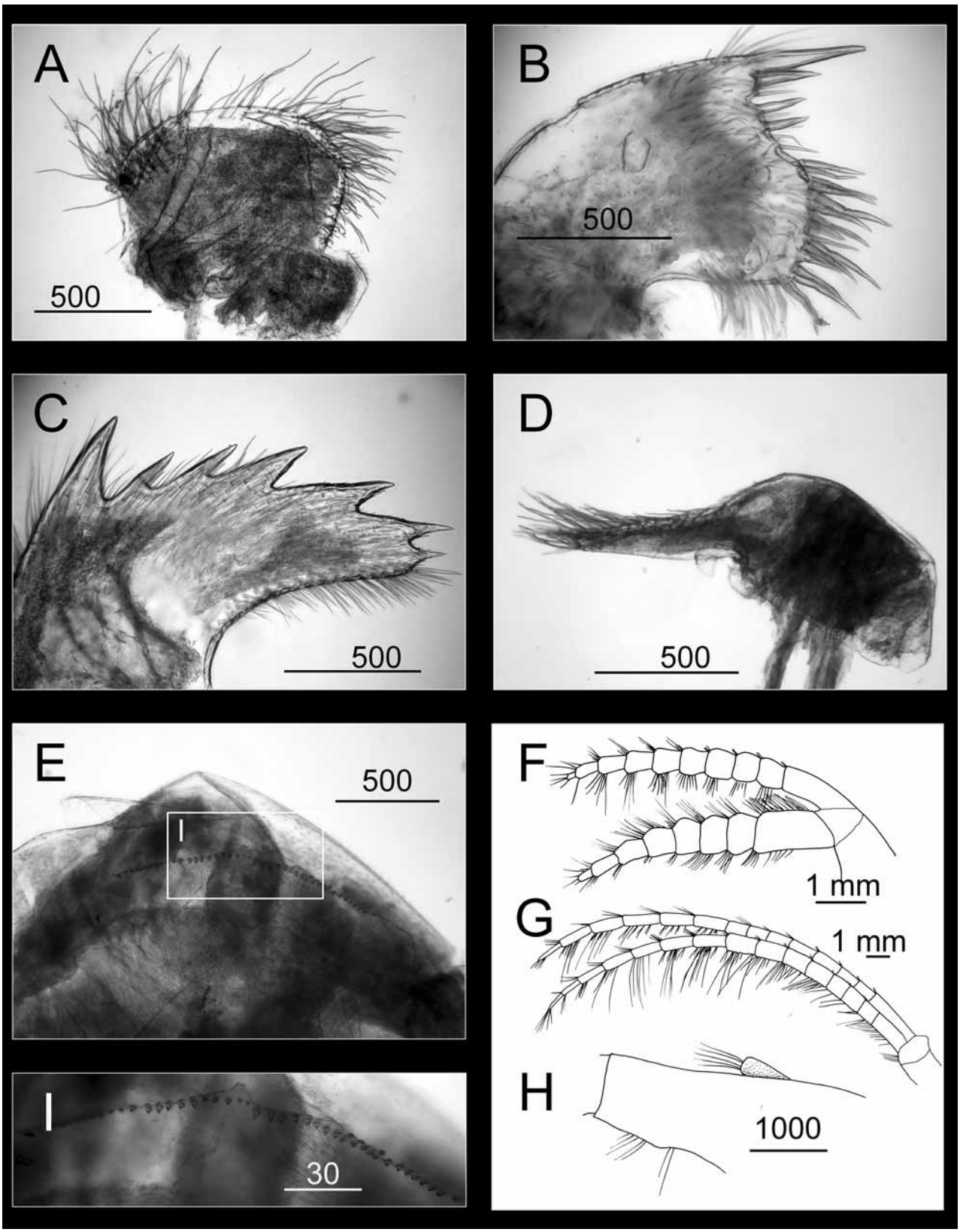

FIGURE 3. *Glyptelasma gigas*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Labrum, F. Cirrus I, G. Cirrus VI, H. Caudal appendage, I. Cutting edge of labrum. Scale bars in μm, except F, G in mm.

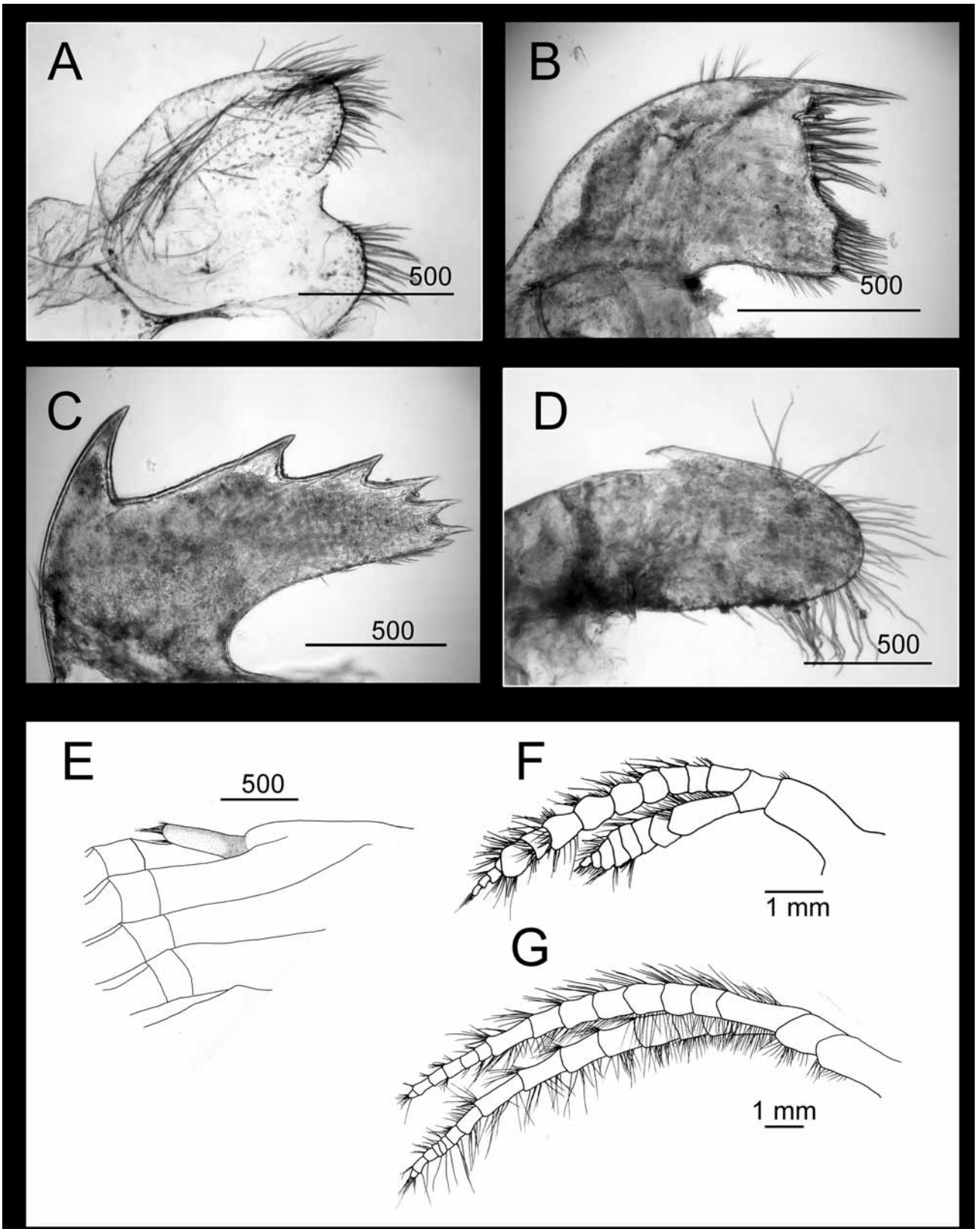

FIGURE 4. *Euscalpellum rostratum*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Caudal appendage, F. Cirrus I, G. Cirrus II. Scale bars in μm, except F, G in mm.

Description. 14 fully calcified, white plates, surfaces with prominent ridges (Fig. 1C); tergum pentagonal, bluntly truncated, occludent and basal margins straight, carinal margin slightly convex (Fig. 1C); scutum with umbo apical, apex projecting over tergum, occludent and basal margins straight, tergal margin slightly concave, occludent and basal margins forming right angle (Fig. 1C); upper latus trapeziform, carinal margin short, straight (Fig. 1C); scutal margin long, concave, umbo apical, apex projecting over scutum (Fig. 1C); rostrolatus quadrangular, scutal and basal margins parallel, umbo at occludent margin of scutum (Fig. 1C); carinolatus irregular shape, subquadrangular, carinal margin concave, other margins straight, umbo at basicarinal angle, in middle portion of carinal margin, angle not extending beyond carina (Fig. 1C); rostrum narrow, small (Fig. 1C). Maxilla triangular, with setae on all margins, maxillary lobe long, naked (Fig. 5A); cutting edge of maxillule notched, 4 cuspidate setae above notch, notch naked, >7 cuspidate setae below notch (Fig. 5B); mandible tri-dentate, teeth sharply pointed (Fig. 5C), lower margin short, with sparse setae, inferior angle setose (Fig. 5C); mandibular palp elongated triangle, superior margin with sparse setae, denser distally (Fig. 5D); cirrus I with rami subequal (Fig. 5F), separated from cirri II–VI; outer ramus longer, slender (10-segmented), inner ramus flattened (8-segmented); cirrus II with outer ramus longer (19-segmented) than inner ramus (14-segmented; Fig. 5H); cirri III–VI similar, rami long, slender, 28–30 segmented (Fig. 5E); caudal appendages short, slender, slightly longer than first segment of basal pedicle of cirrus VI, 7-segmented (Fig. 5G).

Distribution. New Zealand, Australia and Taiwan.

Remarks. This is a new record for Taiwanese waters.

Genus *Tarasovium* Zevina, 1978

Tarasovium orientale Ren, 1983

Figures 1D, 6

Tarasovium orientale Ren, 1983: 76, fig. 1 (13–23). — Liu & Ren, 1985: 201, pl. 2 (15–17). — Liu & Ren, 2007: 246–247, fig. 106.

Material examined. NMNS 005734-00009, 1 specimen, benthic trawl, Tainan County, south west Taiwan (15 Aug. 2005, depth unknown), CL 32.05 mm, CW 21.07 mm, PL 18.66 mm.

Diagnosis. 14 capitular plates, fully calcified; upper latus pentagonal, umbo sub-apical; inframedian latus quadrilateral, umbo close to basal margin; carinolatus horn-shaped, umbo at basicarinal angle, angle extending beyond carina.

Description. Capitulum pale yellow (Fig. 1D), subtriangular, with 14 fully calcified plates, covered by membrane, with sparse setae (Fig. 1D); tergum triangular, umbo apical, occludent and basal margins slightly convex, carinal margin straight; scutum quadrangular, small apex extending beyond margin of tergum, umbo apical, occludent margin convex, basal and upper latus margins concave (Fig. 1D); upper latus pentagonal, umbo subapical (Fig. 1D); rostrolatus narrow quadrangular, wider than high (Fig. 1D); inframedian latus broad, rectangular, umbo close to basal margin (Fig. 1D); carinolatus horn-shaped, umbo at basi-carinal angle, angle extending beyond carina; carina convex, umbo apical (Fig. 1D). Maxilla subtriangular, dense setae along entire margin (Fig. 6A); maxillule not notched, cutting edge with numerous setae (Fig. 6B); mandible with 6 teeth excluding inferior angle (Fig. 6C), lower margin straight, smooth, without setae, inferior angle setose (Fig. 6C); mandibular palp elongated, dense setae along superior margin (Fig. 6D), inferior margin naked. Cirrus I with rami unequal (Fig. 6E), separated from cirri II–VI, outer ramus slender, longer (13-segmented), inner ramus broader, shorter (9-segmented); cirri II–VI similar in morphology (Fig. 6F), outer and inner rami similar lengths, 18–20 segmented; caudal appendage short, 1-segmented, length < height of basal segment of pedicle of cirrus VI.

Distribution. East China Sea and Pacific Taiwanese waters.

Remarks. This is a new record for Taiwanese waters.

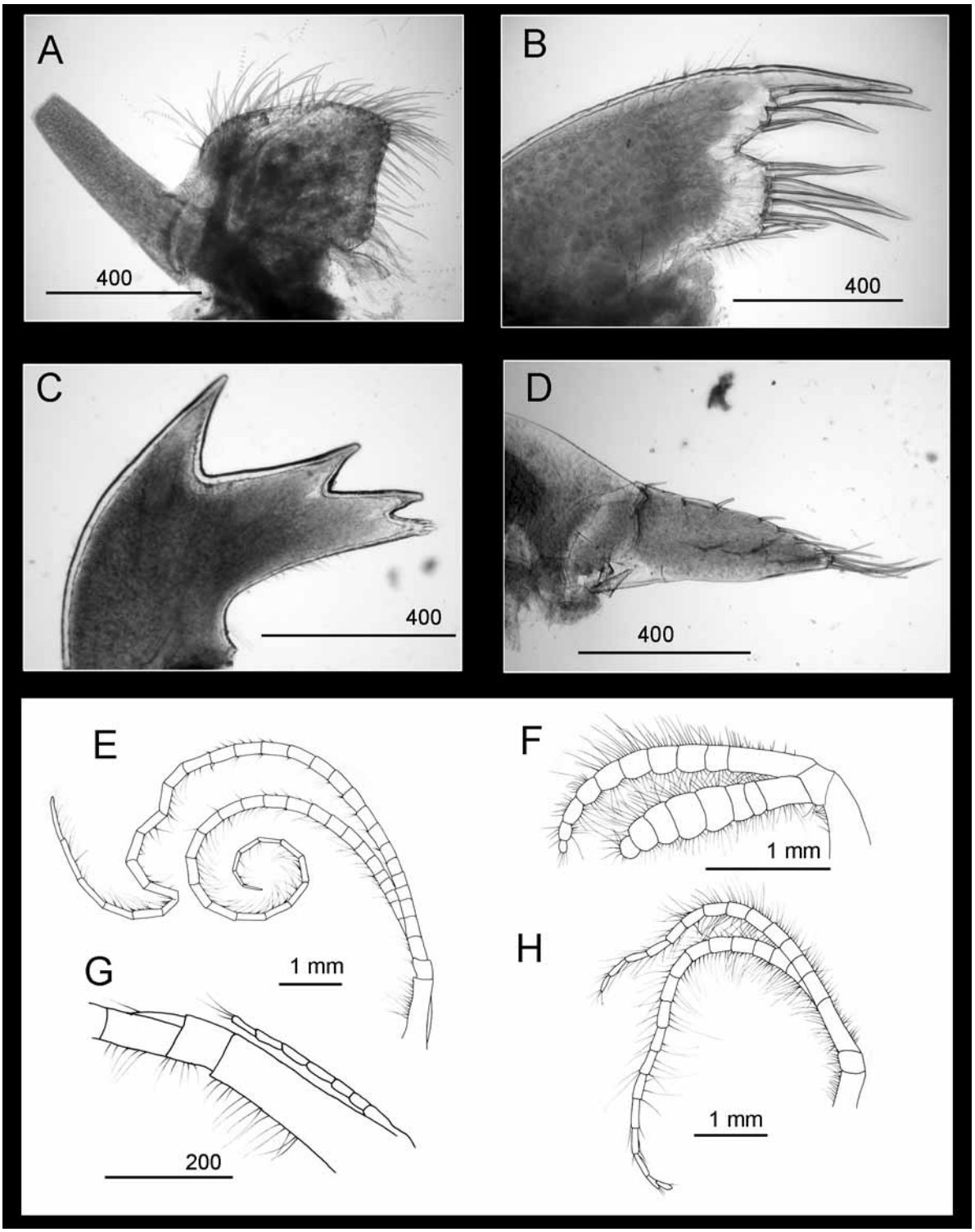

FIGURE 5. *Arcoscalpellum truncatum*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp. Line drawing of E. Cirrus VI, F, Cirrus I, G. Caudal appendages, H. Cirrus II. Scale bars in µm, except E, F, H in mm.

Genus *Trianguloscalpellum* Zevina, 1982

***Trianguloscalpellum diota* (Hoek, 1907)**
Figures 1E, 7, 8

Scalpellum diota Hoek, 1907: 87, pl. 7 figs 15, 15a. — Stubbings, 1936: 22, fig. 9.
Trianguloscalpellum diota. — Zevina, 1981: 315, fig. 239.

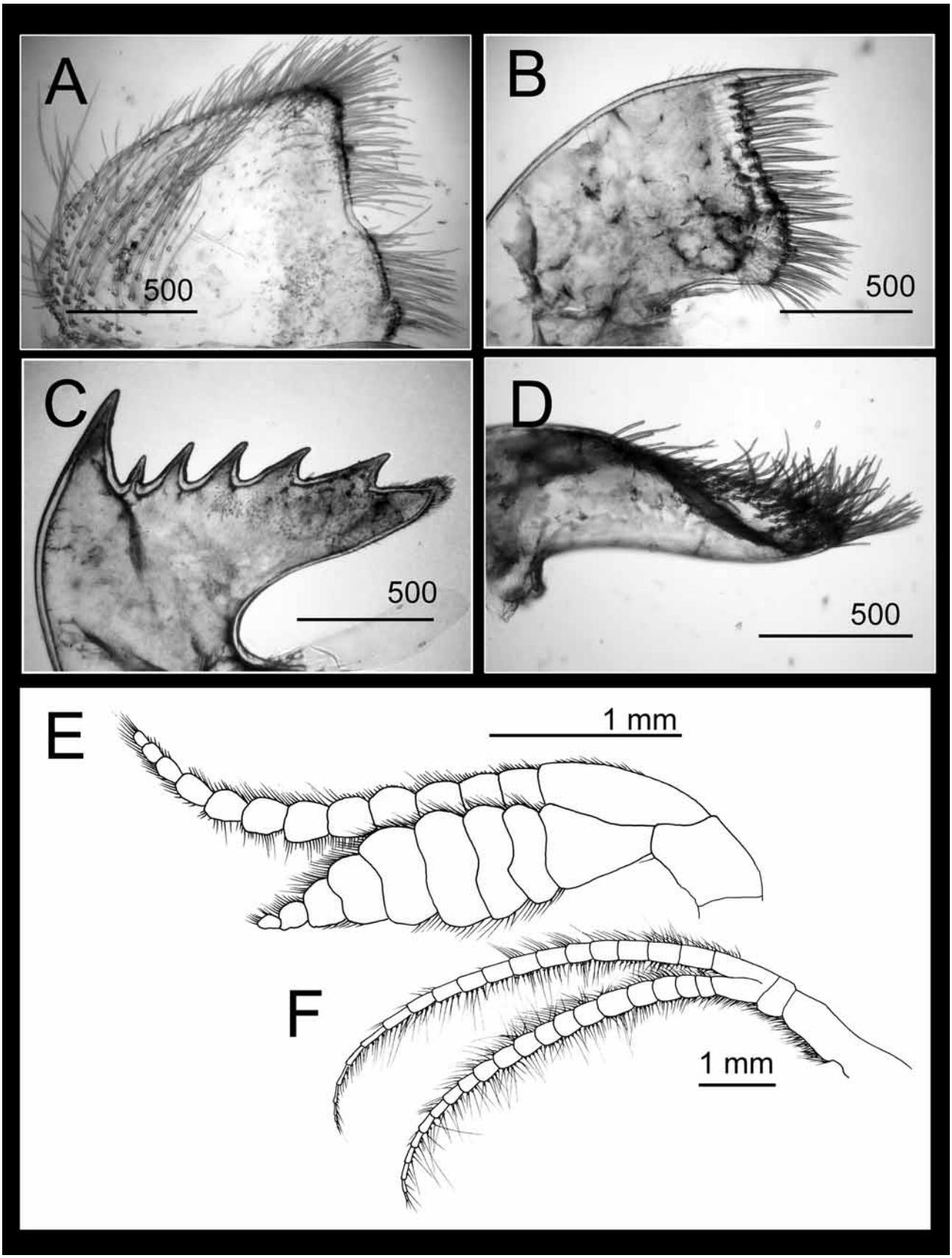

FIGURE 6. *Tarasovium orientale*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Cirrus I, F. Cirrus II. Scale bars in µm except E, F in mm.

Material examined. NMNS 003636-00002, 1 specimen, benthic trawl at Donggang, S. Taiwan (26 Apr. 2001, depth: 250 m), on spine of sea urchin *Stylocidaris renei*, CL 5.01 mm, CW 2.92 mm, PL 2.5 mm.

Diagnosis. Capitulum with 14 fully calcified plates, occludent margin nearly straight, carina margin strongly convex, surfaces with diffused pink patches (colour not faded out after preservation in ethanol); apex of carinolatus strongly recurved, umbo apical.

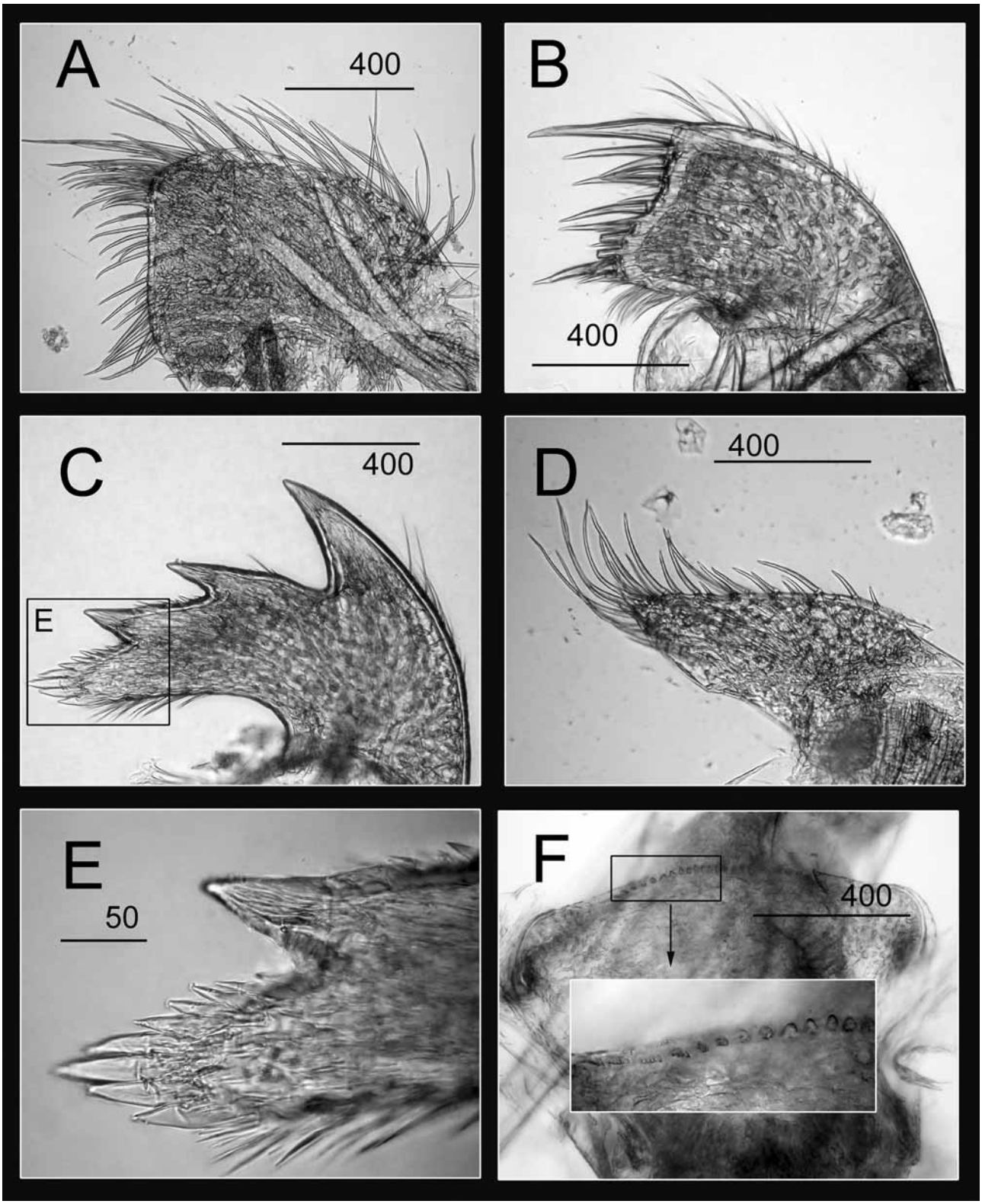

FIGURE 7. *Trianguloscalpellum diota*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Lower margin of mandible, F. Labrum, insert showing the cutting edge. Scale bars in µm.

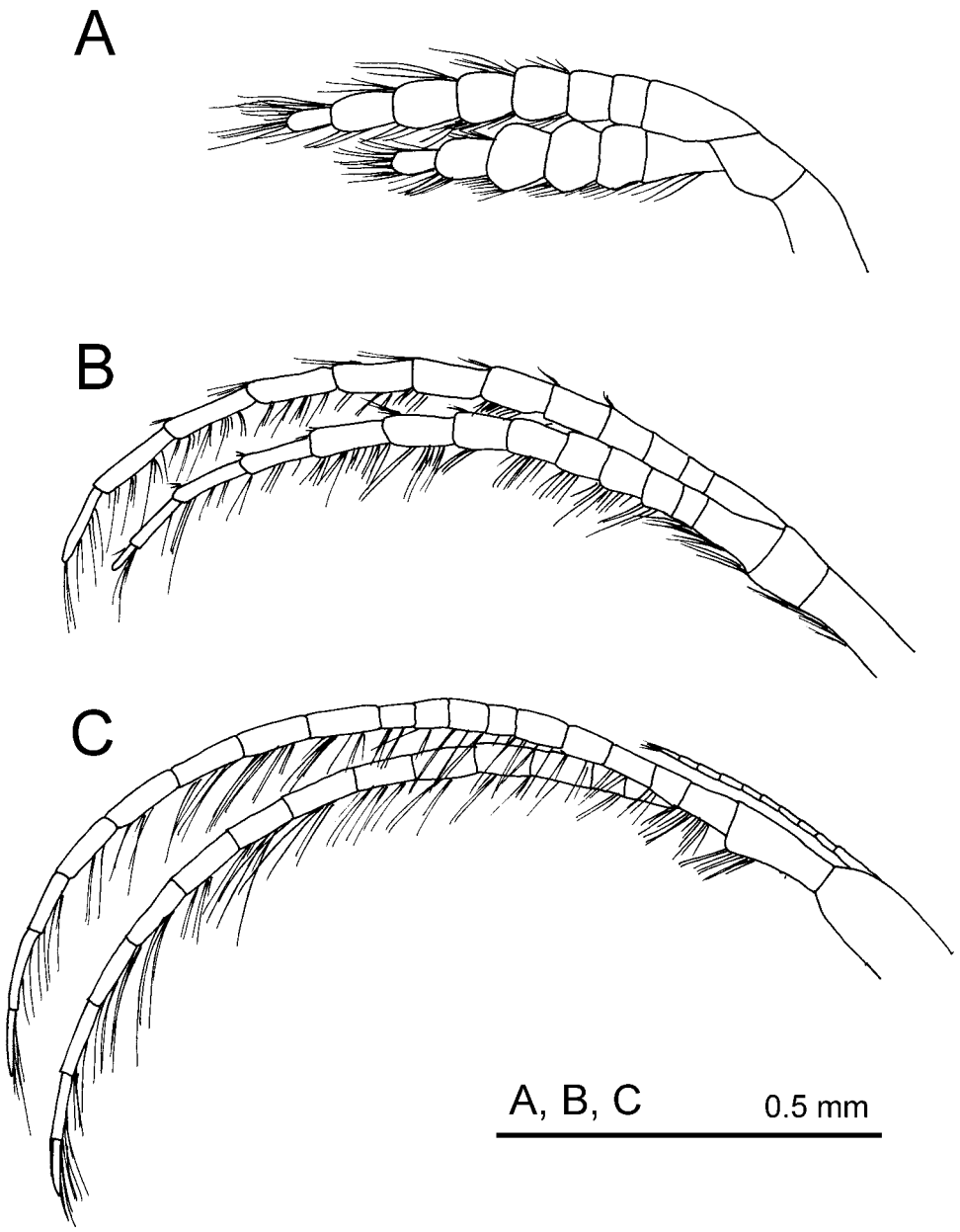

FIGURE 8. *Trianguloscalpellum diota*. Line drawings of A. Cirrus I, B. Cirrus II, C. Cirrus VI, showing the caudal appendage. Scale bars in mm.

Description. Capitulum elongated, diffused light pink color (color not faded out after preservation in ethanol), with 14 capitular plates, covered by setose membrane (Fig. 1E); tergum quadrangular, occludent margin straight, umbo apical, apex acute (Fig. 1E); scutum quadrangular, occludent margin straight, umbo apical, apex slightly overlapping tergum (Fig. 1E); upper latus triangular (Fig. 1E); carinal margin strongly convex, umbo apical (Fig. 1E); inframedian latus small, triangular, umbo apical; rostrolatus quadrilateral, flattened, wider than high (Fig. 1E); carinolatus triangular, apex strongly recurved, umbo apical (Fig. 1E). Maxilla triangular, setae evenly distributed along cutting edge (Fig. 7A); cutting edge of maxillule not notched, with 10 or more cuspidate setae (Fig. 7B); mandible with 3, equally spaced teeth (Fig. 7C), first separated from second and third, cuspidate setae on lower margin, inferior angle with large, cuspidate setae (Fig. 7E); mandibular palp narrow, elongated, serrulate setae on superior margin and distally (Fig. 7D), inferior margin naked; labrum slightly concave, small denticles in straight row (Fig. 7F). Cirrus I short, separated from cirri II–VI, rami subequal (Fig. 8A), outer ramus longer (8-segmented), inner ramus flattened

(6-segmented); cirri II–VI long, slender, similar in length (Fig. 8B, C); cirrus II with outer ramus 12-segmented; inner ramus 13-segmented; cirrus VI with outer ramus 15-segmented, inner ramus 17-segmented; caudal appendages short, length ~ 1/3 inner ramus of cirrus VI, 10-segmented, setae distally (Fig. 8C).

Distribution. Indonesia, the Philippines and Taiwan.

Remarks. This is a new record for Taiwanese waters.

***Trianguloscalpellum hirsutum* (Hoek, 1883)**
Figures 1F, 9

Scalpellum hirsutum Hoek, 1883: 88, pl. 4 fig. 19. — Newman & Ross, 1971: 63, fig. 28.
Trianguloscalpellum hirsutum. — Zevina, 1981: 309, fig. 233.

Material examined. NMNS 005087-00082, 1 specimen, Stn. CP300 (22º17.156'N, 119º59.963'E, 11 Aug. 2005, depth: 960–972 m), CL 20.03 mm, CW 12.76 mm, PL 8.54 mm; CEL-BB-26B, 1 specimen, Stn. CP375 (24º16.240'N, 122º11.720'E, 27 Aug. 2006, depth: 2216–2497 m), CL 21.38 mm, CW 19.42 mm, PL 13.78 mm; CEL-BB-63, 1 specimen, Stn. CP371 (24º28.521'N, 122º12.821'E, 26 Aug. 2006, depth: 582–613 m), CL 21.5 mm, CW 13.2 mm, PL 12.03 mm.

Diagnosis. Capitulum with 14 fully calcified plates; surface of capitulum and peduncle covered by dense setae; tergum with long, sharp apex, upper latus triangular

Description. Capitulum with 14 fully calcified plates, surfaces covered by long setae (Fig. 1F); tergum large, elongated rhomboid, higher than wide, apex apical, produced, acute, umbo apical, occludent margin straight; scutum quadrangular, occludent and tergal margins convex, lateral and basal margin straight, apex produced at tip of occludent margin, umbo apical (Fig. 1F); upper latus triangular, carinal margin straight; inframedian latus triangular, subequilateral, umbo apical; rostrolatus flattened, width twice height (Fig. 1F); carinolatus horn-shaped, apex apical, produced, touching carina. Peduncle short, scales in longitudinal rows. Maxilla bilobed, setae in 3 main clusters (Fig. 9A); maxillule not notched, cutting edge with ~ 19 cuspidate setae on cutting edge (Fig. 9B); mandible with 3 equally spaced teeth, lower margin straight, smooth, inferior angle blunt with dense setae (Fig. 9C); mandibular palp elongated, setae on superior margin and apically (Fig. 9D); labrum concave, cutting edge smooth, with fine setae, teeth absent (Fig. 9E, I). Cirrus I separated from cirri II-VI, rami unequal, outer ramus longer, slender, (13-segmented), inner ramus shorter, broad (7-segmented) (Fig. 9F); cirrus II with rami subequal, outer ramus 23-segmented, inner ramus 25-segmented (Fig. 9G); cirri III–VI similar length, longer than cirri I and II, cirrus IV with outer ramus 26-segmented, inner ramus 25-segmented (Fig. 9H); caudal appendage 1-segmented, appendage length < height of basal segment of pedicle of cirrus VI.

Distribution. Borneo, Antarctica and Taiwan.

Remarks. This is a new record for Taiwanese waters. *Trianguloscalpellum hirsutum* is morphologically close to *Arcoscalpellum foresti* Rosell, 1989, in that both species have setae on the whole body, and in the shape of the tergum. *Trianguloscalpellum hirsutum* has a triangular upper latus, whilst that of *A. foresti* is quadrangular. The umbo of the carinolatus of *A. foresti* is located in the middle of the carinal margin, whilst that of *T. hirsutum* is located apically.

***Trianguloscalpellum regium* (Thomson, 1878)**
Figures 1G, 10

Scalpellum regium Wyville Thomson, 1878: 11, figs 2–3. — Hoek, 1883: 106: pl. 4 figs 3–5. — Pilsbry, 1907: 28, pl. 3 figs 4, 5. — Gruvel, 1920: 30, pl. 1 fig. 7.
Trianguloscalpellum regium regium. — Zevina, 1981: 309, fig. 234.

Material examined. CEL-BB-46C, 1 specimen, Stn. CP375 (24º16.240'N, 122º11.720'E, 27 Aug. 2006, depth: 2216–2497 m), CL 36.3 mm, CW 22.50 mm, PL 16.78 mm.

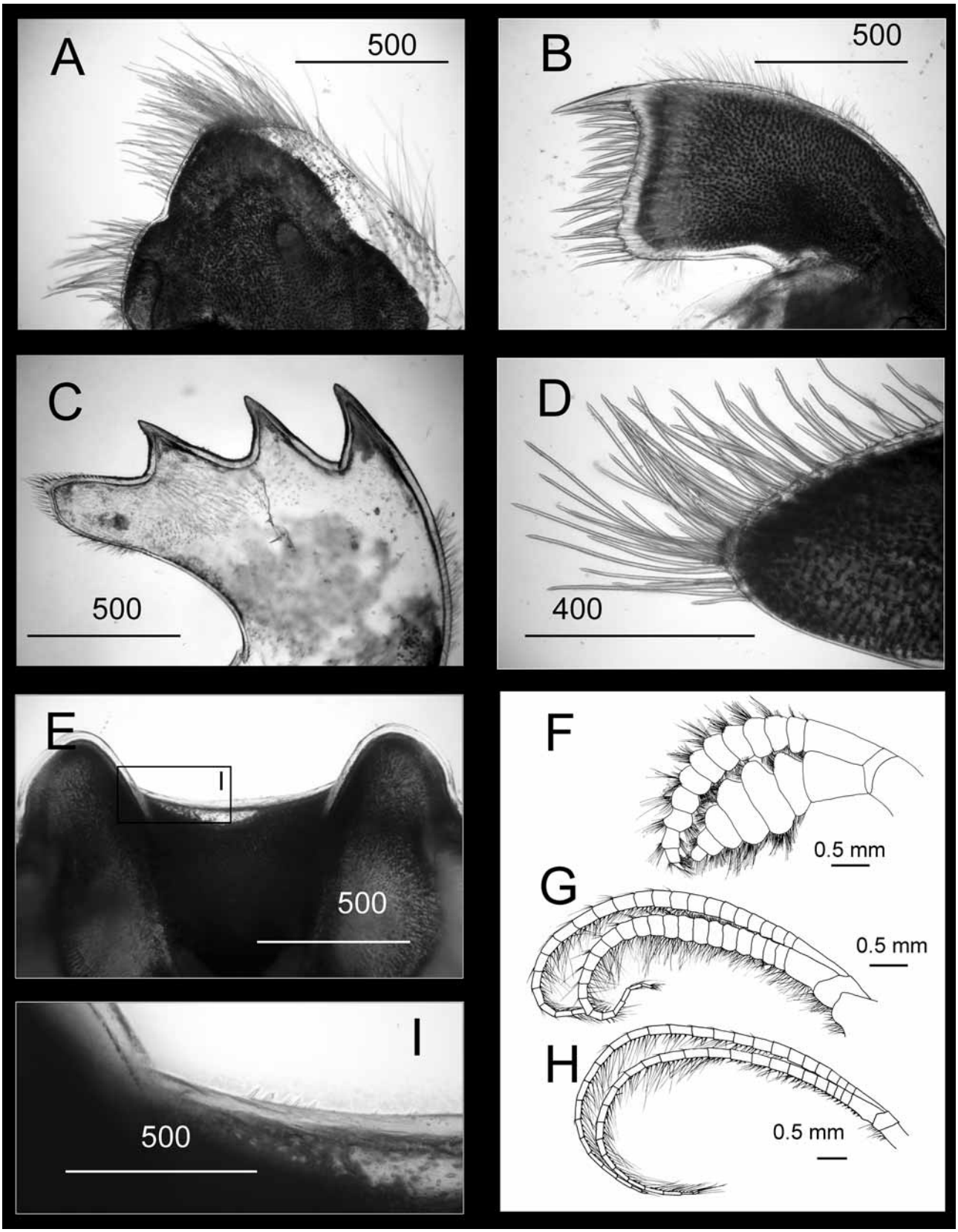

FIGURE 9. *Trianguloscalpellum hirsutum*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Labrum, F. Cirrus I, G. Cirrus II, H. Cirrus IV, I. Cutting edge of labrum. Scale bars in µm, except F–H in mm.

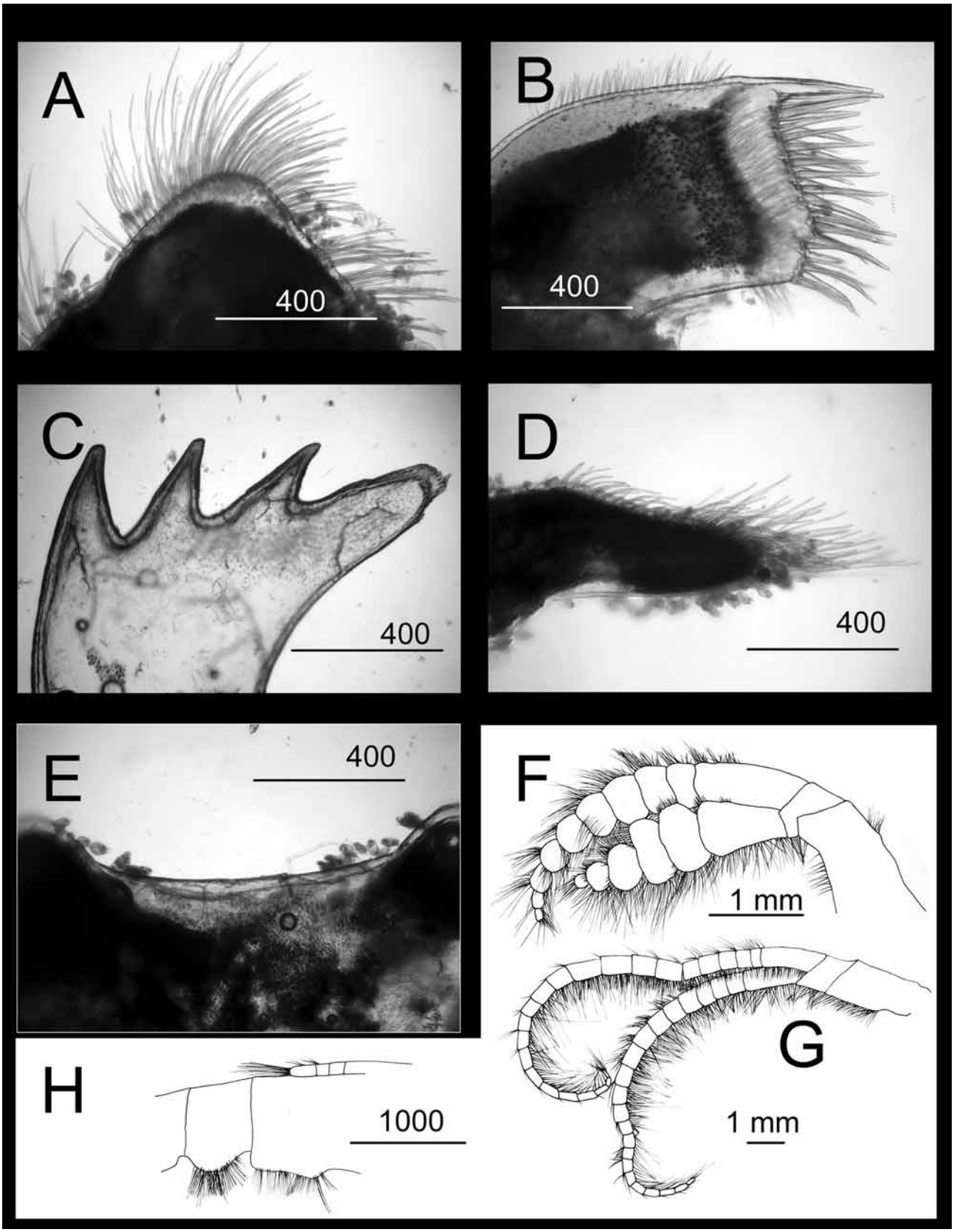

FIGURE 10. *Trianguloscalpellum regium*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Labrum, F. Cirrus I, G. Cirrus II, H. Caudal appendage. Scale bars in μm, except F, G in mm.

Diagnosis. Capitulum quadrangular, covered by smooth membrane, 14 fully calcified plates; tergum large, triangular, carinal margin convex, occludent margin straight, umbo apical; scutum quadrangular, higher

than wide, apex produced at junction of occludent and tergal margins, umbo apical; carinolatus higher than wide, curved, apex produced, umbo apical.

Description. Capitulum quadrangular, 14 plates, covered by smooth membrane (Fig. 1G); tergum large, triangular, carinal margin convex, occludent margin straight, umbo apical; scutum quadrangular, higher than wide, apex produced at junction of occludent and tergal margins, umbo apical (Fig. 1G); upper latus triangular, tergal and lateral margins convex, scutal margin concave (Fig. 1G); inframedian latus equilateral triangle, umbo apical; rostrolatus very narrow, wider than high; carinolatus higher than wide, curved, apex produced, umbo apical (Fig. 1G); carina bowed, roof flat; peduncle with densely packed, concentric scales (Fig. 1G). Maxilla densely setose (Fig. 10A); cutting edge of maxillule not notched, >22 large cuspidate setae along cutting edge (Fig. 10B); mandible with 3 evenly separated teeth excluding inferior angle, lower margin long, naked, inferior angle covered by dense setae (Fig. 10C); mandibular palp narrow, elongated, setae along superior margin, inferior margin naked (Fig. 10D); labrum concave, cutting edge smooth, teeth absent (Fig. 10E). Cirrus I separated from remaining cirri, rami unequal, outer ramus longer, slender, 10-segmented, inner ramus broader, shorter, 6-segmented (Fig. 10F); cirrus II with rami equal, both rami 22-segmented (Fig. 10G); cirrus VI with rami equal, outer and inner rami 33-segmented; caudal appendage short, 4-segmented, length < height of basal segment of pedicle of cirrus VI (Fig. 10H).

Distribution. Cosmopolitan: Atlantic and Pacific Oceans, including Taiwan.

Remarks. This is a new record for Taiwanese waters. This species was named by the chief scientist, Professor Sir Charles Wyville Thomson (see Hoek, 1883: 106), but no detailed species description was provided. Hoek (1883) fully described the species and retained Thomson's name, *Scalpellum regium*.

***Trianguloscalpellum weltnerianum* (Pilsbry, 1911)**
Figures 1H, 11

Scalpellum weltnerianum Pilsbry, 1911: 64, pl. 9 figs 5–7.
Trianguloscalpellum weltnerianum. — Zevina, 1981: 306, fig. 230.

Material examined. CEL-BB-88, 1 specimen, Stn. CP320 (20º50.090'N, 117º27.170'E, 19 Aug. 2005, depth: 720–730 m), CL 8.31 mm, CW 3.57 mm, PL 3.56 mm.

Diagnosis. Capitulum elongated, length twice width; 14 capitular plates, white, surfaces sculptured with radial fine riblets, setae absent; rostrum oval, large; inframedian latus narrow, triangular; peduncle covered with strongly imbricating, laterally interlocking, white scales.

Description. Capitulum elongated, length twice width; 14 white capitular plates, surfaces striated with radial riblets (Fig. 1H); tergum higher than wide, quadrangular (Fig. 1H); scutum quadrilateral, umbo apical, occludent and basal margins straight, intersecting at right angles (Fig. 1H); upper latus quadrangular, higher than wide, scutal margin concave, basal margin short (Fig. 1H); inframedian latus triangular, height twice width, umbo apical; carinolatus upwardly curved, umbo apical (Fig. 1H); rostrolatus quadrangular; rostrum large, oval; carina bowed, roof flat (Fig. 1H). Peduncle covered with strongly imbricating, laterally interlocking, white scales. Maxilla subquadrangular, bilobed, setae clustered into 3 regions (Fig. 11A); maxillule with cutting edge narrow, notched, 4 large cuspidate setae above notch, notch naked, 5 cuspidate setae below notch (Fig. 11B); mandible tridentate, first tooth separated from second and third, lower margin very short, inferior angle pectinated with cuspidate setae (Fig. 11C); mandibular palp with setae apically and along superior margin, inferior margin naked (Fig. 11D). Cirrus I with rami unequal, separated from cirri II–VI, outer ramus longer, slender, 10-segmented, inner ramus slightly broader, 6-segmented (Fig. 11E); cirri II–VI long, slender; cirrus II with outer ramus 12-segmented, inner ramus 12-segmented (Fig. 11F); cirrus III with outer ramus 12-segmented, inner ramus 11-segmented; cirrus VI with outer ramus 14-segmented, inner ramus 15-segmented (Fig. 11G); caudal appendage very short, 1-segmented, length < basal segment of pedicle of cirrus VI (Fig. 11H).

Distribution. Japanese and Taiwanese waters.

Remarks. This record of *T. weltnerianum* is a new record for Taiwanese waters. Pilsbry (1911) noted that *T. weltnerianum* is morphologically close to *T. album* (Hoek, 1883) collected from the Malay Archipelago. *Trianguloscalpellum weltnerianum* differs from *T. album* in having the surfaces of the capitular plates striated, whilst those of *T. album* are smooth (Hoek, 1883; Pilsbry, 1911). At present, this species is only reported to live on crinoids, suggesting an association relationship.

Genus *Verum* Zevina, 1981

Verum novaezelandiae (Hoek, 1907)

Figures 1I, 12, 13

Scalpellum novaezelandiae Hoek, 1883: 124, pl. 5 figs 7, 8.
Scalpellum poculum Hoek, 1907: 100, pl. 8 figs 4, 4a.
Verum novaezelandiae. — Zevina, 1981: 288, fig. 165.

Material examined. CEL-BB-76, 2 specimens, Stn. CP364 (22º06.335'N, 121º08.224'E, 24 Aug. 2006, depth: 1260–1275 m), on sunken wood, CL 4.22–6.86 mm, CW 1.86–3.15 mm, PL 0.94–0.96 mm.

Diagnosis. Capitulum elongated, higher than wide, 14 fully calcified, white, plates; inframedian latus pentagonal or vase-shaped, umbo sub-basal; carinolatus with basicarinal angle not extending beyond carina.

Description. Capitulum elongated, flattened, 14 fully calcified, closely packed, smooth, white plates (Fig. 1I); tergum triangular, umbo apical, occludent and scutal margins straight, intersecting at right angles; scutum quadrangular, apex produced at tergal margin, umbo apical, occludent margin straight, lateral margin slightly convex; upper latus pentagonal, apex produced at tergal-scutal angle, umbo apical (Fig. 1I); inframedian margin shortest; inframedian latus pentagonal or vase-shaped, umbo submedial; rostrolatus quadrangular, wider than high (Fig. lI); carinolatus higher than wide, umbo at basicarinal angle, angle not extending beyond scutum; carina bowed, roof flat; rostrum small, oval-shaped; peduncle covered by dense scales (Fig. 1I). Maxilla bilobed, setae clumped into 2 main clusters, sparse setae on superior margin (Fig. 12A); cutting edge of maxillule notched, 4 cuspidate setae above notch, notch naked, > 6 cuspidate setae below notch (Fig. 12B); mandible with 3 large teeth, first separated from second and third (Figs 12C, G); lower margin short, pectinated, inferior angle pectinated by >3 large, cuspidate setae (Fig. 12E); mandibular palp triangular, setae along superior margin and apically, inferior margin naked (Fig. 12D); labrum with fine, sharp teeth on cutting edge (Figs 12F, H). Cirrus I separated from remaining cirri, rami unequal; outer ramus slender, longer, 9-segmented, inner ramus broader, short, 6-segmented (Fig. 13A); cirri II–VI with rami subequal; cirrus II with outer ramus 13-segmented, inner ramus 14-segmented (Fig. 13B); cirrus VI with outer ramus 15-segmented, inner ramus 17-segmented (Fig. 13C); caudal appendage very short,1-segmented, length < height of basal segment of pedicle of cirrus VI (Fig. 13D).

Distribution. Pacific Ocean, including Taiwan.

Remarks. This is a new record for Taiwanese waters.

Sub-family Meroscalpellinae Zevina, 1978

Genus *Annandaleum* Newman & Ross, 1971

Annandaleum japonicum biramosum (Pilsbry, 1911)

Figures 2A, 14, 15

Scalpellum japonicum Hoek, 1883: 67, pl. 3 figs 9, 10.
Scalpellum japonicum biramosum Pilsbry, 1911: 68, pl. 11 figs 1, 2.
Annandaleum japonicum. — Newman & Ross, 1971: 122.

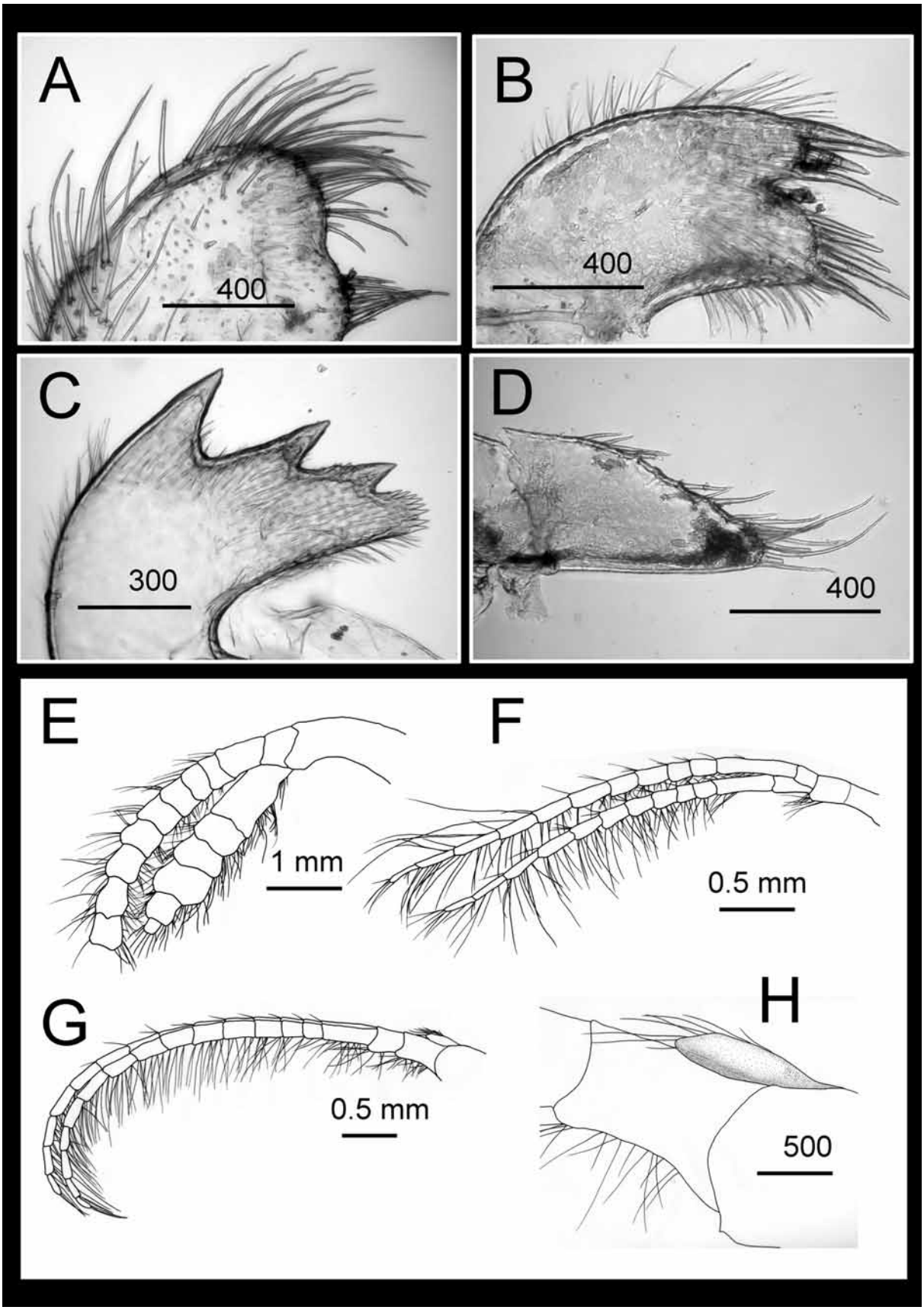

FIGURE 11. *Trianguloscalpellum weltnerianum*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Cirrus I, note the distal segment of the outer ramus was broken during dissection, F. Cirrus II, G. Cirrus VI, H. Caudal appendage. Scale bars in μm, except E, F, G in mm.

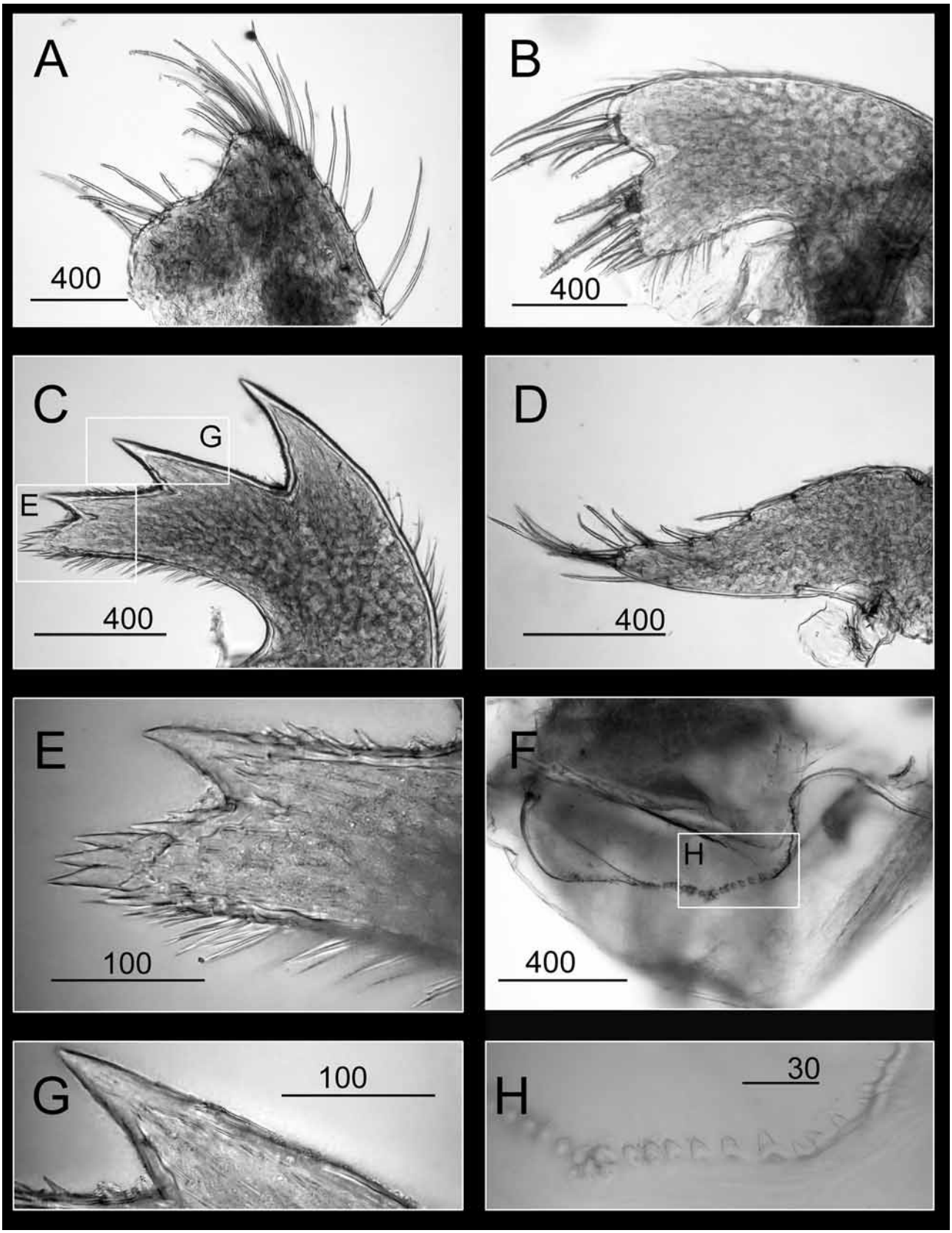

FIGURE 12. *Verum novaezelandiae*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Lower margin of mandible, F. Labrum, G. Second tooth of mandible, H. Cutting edge of mandible, showing fine teeth. Scale bars in µm.

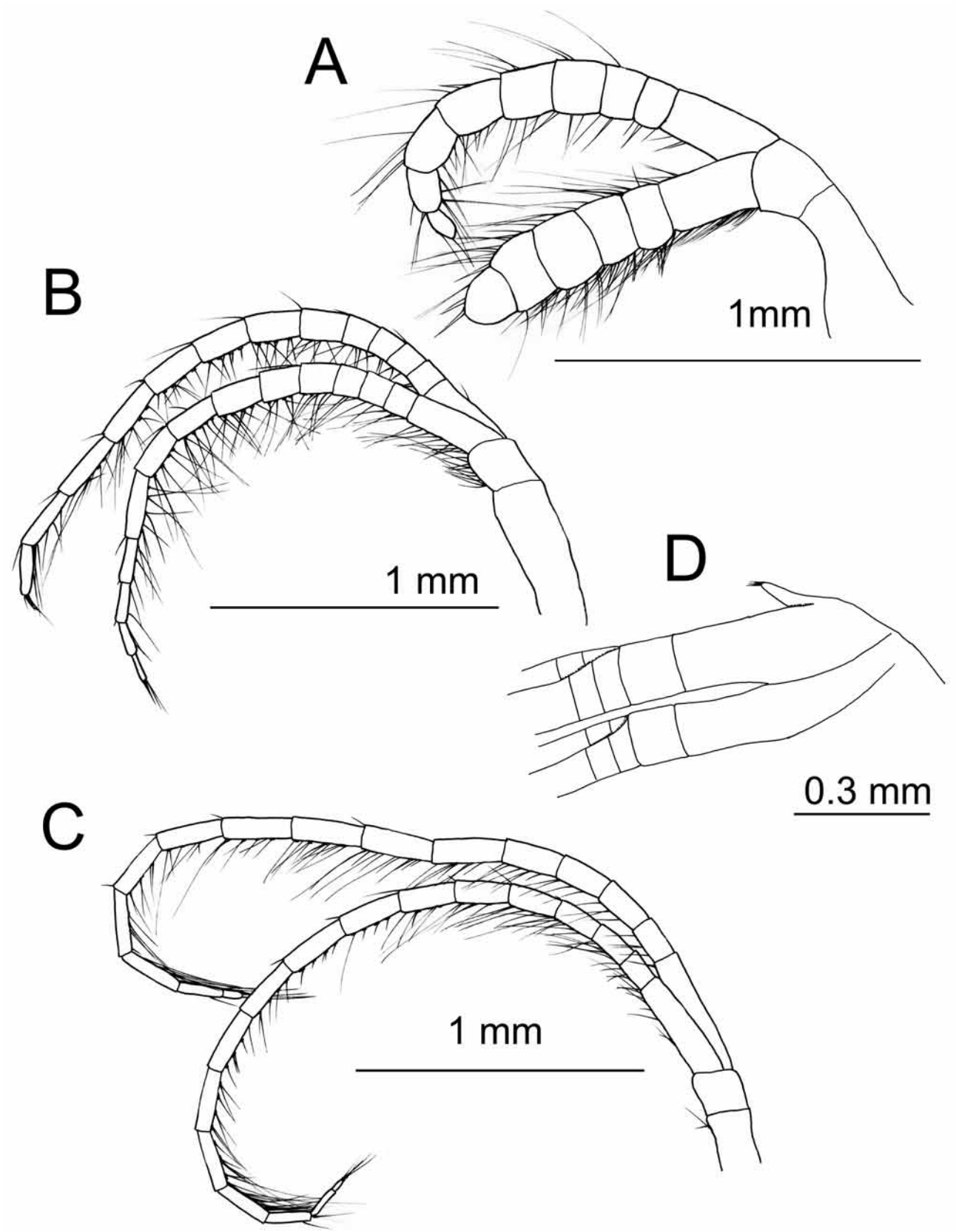

FIGURE 13. *Verum novaezelandiae*. A. Cirrus I, B. Cirrus II, C. Cirrus VI, D. Caudal appendage.

Material examined. NMNS 003636-00062, 1 specimen, Stn. CP130 (22º18.77'N, 120º6.99'E, 22 Aug. 2001, depth: 728–709 m), CL 19.42 mm, CW 11.57 mm, PL 8.26 mm; CEL-BB-87, 1 specimen, Stn. CP196 (24º51.75'N, 122º3.75'E, 11 Sept. 2002, depth: 636–787 m). CL 20.75 mm, CW 11.95 mm, PL 7.81mm.

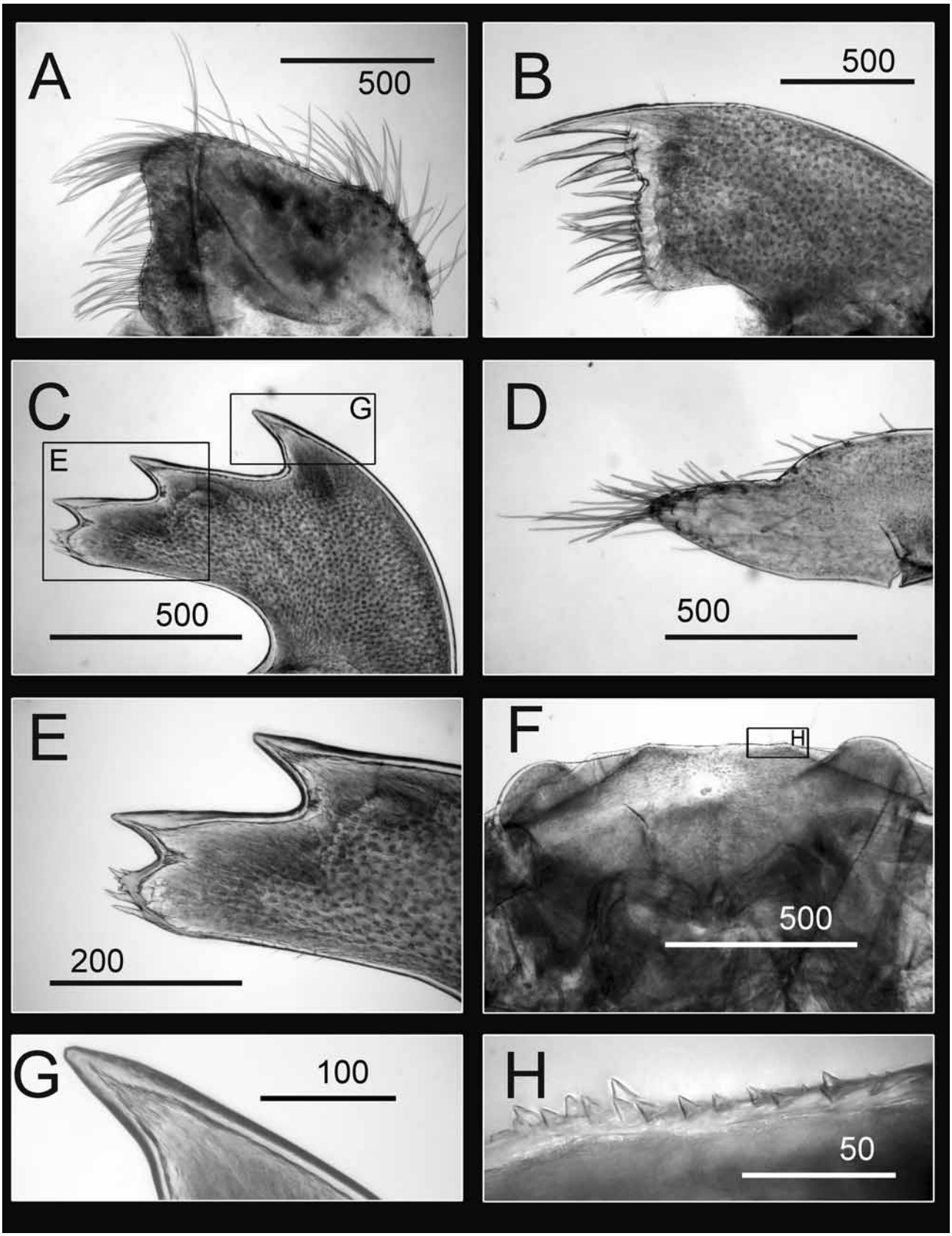

FIGURE 14. *Annanadaleum japonicum biramosum*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Lower margin of mandible, F. Labrum, G. First tooth of mandible, H. Cutting edge of mandible, showing fine teeth. Scale bars in μm.

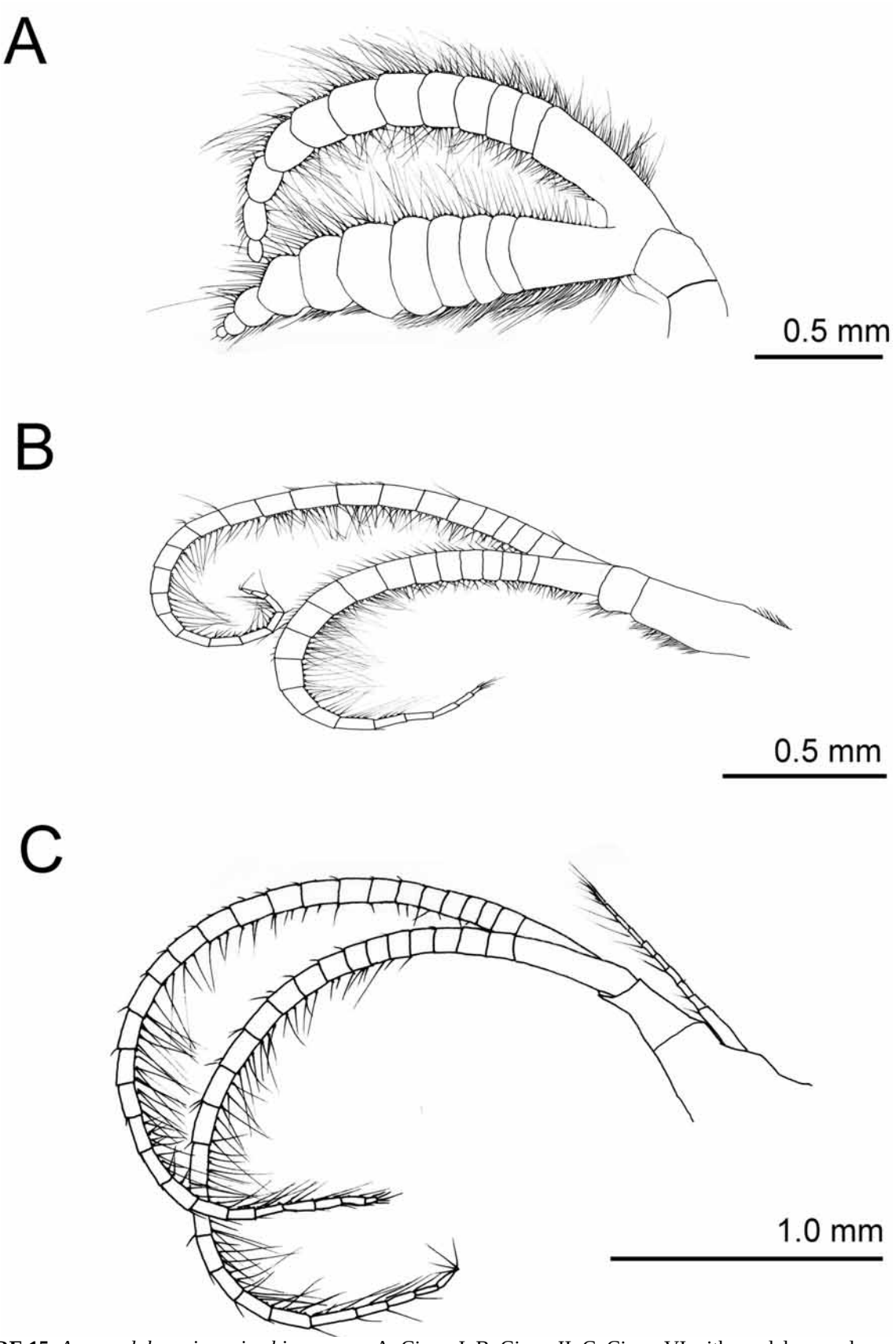

FIGURE 15. *Annanadaleum japonica biramosum*. A. Cirrus I, B. Cirrus II, C. Cirrus VI with caudal appendage.

Diagnosis. Opercular plates not completely calcified; tergum inverted V-shaped; scutum with apicolateral arm ~ 1/3 length of tergal margin (Fig. 2A); upper latus irregular, subtriangular, branch extending along scutal

margin, bifid, simple on carinal side; inframedian latus higher than wide, vase-shaped, umbo submedial; caudal appendage relatively long, 10-segmented.

Description. Capitulum covered by semi-transparent, pale yellow membrane (Fig. 2A); 14 partially calcified capitular plates, separated by broad, chitinous interspaces (Fig. 2A); tergum inverted V-shaped, umbo apical, branch at carinal margin longer than occludent margin branch (Fig. 2A); scutum long, narrow, umbo apical, slightly overlapping tergal margin, lateral margin with apicolateral arm ~ 1/3 length of tergal margin; upper latus irregular, subtriangular, branch at scutal margin bifid, branch at carinal margin simple (Fig. 2A); rostrum very small, narrow; rostrolatus quadrangular, wider than high (Fig. 2A); inframedian latus higher than wide, vase-shaped, umbo submedial (Fig. 2A); carinolatus V-shaped, lateral margin bifid; carina bowed, roof flat, width greater in basal region. Maxilla subtriangular, margin covered with dense setae in 3 clusters (Fig. 14A); maxillule slightly notched, 3 long and 1 short cuspidate setae above notch, notch naked, 9 cuspidate setae below notch (Fig. 14B); mandible with 3 teeth (Fig. 14C), first tooth separated from second and third (Fig. 14E, G), lower margin very short, setae absent, inferior angle blunt with 5 setae (Fig. 14E); mandibular palp subtriangular, elongated, setae distally and along superior margin, inferior margin naked (Fig. 14D); cutting edge of labrum straight, with very fine teeth (Fig. 14F, H). Cirrus I separated from cirri II–VI; rami of cirrus I subequal, outer ramus longest, 12 segmented (Fig. 15A), inner ramus broader, shorter, 11 segmented; cirri II–VI with rami subequal; cirrus II with outer ramus 25-segmented, inner ramus 21-segmented (Fig. 15B), cirrus VI with outer ramus 29-segmented, inner ramus 26-segmented (Fig. 15C); caudal appendage ~ 1/3 length of cirrus VI, 10-segmented (Fig. 15C).

Distribution. Pacific waters in Japan and Taiwan.

Remarks. Pilsbry (1911) identified the sub-species *biramosum* of *Annandaleum japonicum*. Compared to *Annandaleum japonicum, A. j. biramosum* has the umbo of the carina closer to the upper end of the plate with the branch of the upper latus extending along the scutal margin bifid and simple on the carinal side. The inframedian latus is less excavated along its upper border in *A. j. biramosum* (Pilsbry, 1911). However, Pilsbry (1911) doubted that such difference in plate morphology represented intra-specific variation. In the present study, the maxillule and mandible of *A. j. biramosum* are similar to Pilsbry's illustration of the maxillule and mandible of *A. japonicum* (Pilsbry, 1911). The taxonomic status and morphological variation of *A. japonicum* and *A. j. biramosum* should be evaluated using molecular techniques. The present record of *A. j. biramosum* is a new record for Taiwanese waters.

Genus *Litoscalpellum* Newman & Ross, 1971

Litoscalpellum spinosus sp. nov.

Figures 2B, 16, 17

Material examined. Holotype: NMNS 6058-001, 1 specimen, Stn. CP238 (25º12.28'N, 123º1.85'E, 23 Jul. 2004, depth: 1650–1689 m), CL 27.75 mm, CW 17.54 mm, PL 11.85 mm.

Diagnosis. Capitulum with 14 partially calcified plates; plates white, surfaces covered by dense, short setae; inframedial latus not touching upper latus; somatic body with dorsal thoracic, sharp processes, located at bases of cirri III and IV.

Description. Capitulum with 14 partially calcified plates, plates white, surfaces covered by dense, short setae, separated by chitinous interspaces (Figs 2B, 17A); tergum triangular, umbo apical, apex slightly truncated, scutal, occludent and carinal margins straight (Figs 2B, 17A); scutum quadrangular, higher than wide, apex produced at tergal margin, slightly overlaying tergum, umbo apical, occludent margin slightly convex, lateral, basal and tergal margins straight (Figs 2B, 17A); upper latus quadrangular, carinal margin shortest, tergal and lateral margins convex, scutal margin slightly concave; rostrum very narrow, small (Figs 2B, 17A); inframedian latus triangular, wider than high, not touching upper latus, umbo apical; rostrolatus quadrangular, occludent and scutal margins forming right angle, scutal margin longest; carinolatus subtriangular, lateral margin convex, umbo at basicarinal angle, angle not extending beyond carina; carina

bowed, roof flat, umbo apical (Figs 2B, 17A). Peduncle with white, concentric scales (Fig. 2B). Maxilla quadrangular, setae divided into 3 clusters (Fig. 16A); cutting edge of maxillule short, notched, 3 large, long cuspidate setae and 2 short, cuspidate seta above notch, several large cuspidate setae below notch (Fig. 16B); mandible with 3 teeth, first widely separated from second and third, lower margin smooth, inferior angle sharp with dense setae (Figs 16C, E, G); mandibular palp elongated, narrow, setae distally and along superior margin, inferior margin naked (Fig. 16D); labrum strongly concave, cutting edge with fine, sharp teeth (Figs 16F, H). Cirrus I separated from cirri II–VI, rami subequal, outer ramus slender, longer, 13-segmented, inner ramus broader, shorter, 8-segmented (Fig. 17C); cirri II–VI with rami subequal; cirrus II with outer ramus 19-segmented, inner ramus 30-segmented (Fig. 17E); cirrus III with outer ramus 18-segmented; inner ramus 21-segmented; cirrus IV with outer ramus 25-segmented, inner ramus 7-segmented; cirrus V with outer ramus 25-segmented, inner ramus 25-segmented; cirrus VI with outer ramus 29-segmented, inner ramus 32-segmented; caudal appendage very short, 1-segmented, length < height of basal segment of cirrus VI (Figs 17B, D); somatic body with dorsal thoracic, sharp processes, located at bases of cirri III and IV (Fig. 17B).

Etymology. The name *spinosus* is to denote the dorsal thoracic, sharp processes, located at the bases of cirri III and IV, a diagnostic character of this species.

Distribution. Presently known only from the type locality.

Remarks. The capitular morphology of *Litoscalpellum spinosus* **sp. nov.** is similar to *L. affbricatum* Foster, 1978. However, the capitulum of *L. affbricatum* is covered by a naked, smooth integument (Foster, 1978) whilst that of *L. spinosus* **sp. nov.** is covered by dense, short hairs. The rostrum of *L. affbricatum* is large, wide and triangular (Fig. 17G; Foster, 1978), whilst the rostrum of *L. spinosus* **sp. nov.** is narrow (Fig. 17F). The somatic body of *L. affbricatum* is not reported to have dorsal thoracic, sharp processes at the bases of cirri III and IV. Previously, no *Litoscalpellum* species has been reported to possess dorsal thoracic, sharp processes.

Subfamily Scalpellinae Pilsbry, 1907

Genus *Scalpellum* Leach, 1817

***Scalpellum stearnsii* Pilsbry, 1890**
Figures 2C, 18

Scalpellum stearnsii Pilsbry, 1890: 441. — Broch, 1922: 235, fig. 6. — 1931: 16. — Nilsson-Cantell, 1934: 33. — Hiro, 1939c: 237. — Rosell, 1981: 279, pl. Ie.
Scalpellum stearnsi. — Gruvel, 1905: 44, fig. 46.

Material examined. CEL-BB-56, 1 specimen, Nan Fang Ao Fishing market (27 May 2004), CL 34.6 mm, CW 22.84 mm, PL 26.27 mm.

Diagnosis. Carina strongly bowed; tergum triangular; scutum with umbo at tergo-occludent angle; inframedian latus pentagonal, umbo sub-basal; carinolateral horn-shaped, umbo at basicarinal angle, angle extending beyond carina.

Description. Capitulum almost square-shaped; 14 perfectly calcified plates, covered by yellow membrane (Fig. 2C); tergum triangular, umbo apical, tergal margin slightly convex (Fig. 2C); scutum quadrilateral, lateral margin concave (Fig. 2C); upper latus pentagonal (Fig. 2C); inframedian latus pentagonal, smaller than upper latus, umbo submedial (Fig. 2C); carinolatus strongly curved, horn-shaped, extending beyond carina, umbo apical (Fig. 2C); rostrolatus wider than high, narrow; rostrum small (Fig. 2C); carina strongly bowed, thick. Peduncle long, cylindrical, covered by calcified scales (Fig. 2C); peduncular scales arranged in concentric patterns (Fig. 2C). Maxilla subtriangular with fine setae (Fig. 18A); maxillule without a clear notch, > 35 strong cuspidate setae on cutting edge (Fig. 18B); mandible with 5 major teeth excluding inferior angle (Fig. 18C), lower margin with fine denticles, inferior angle terminating in dense setae (Fig. 18C); mandibular palps elongated, narrow, with serrulate-type setae on superior margin (Fig. 18D); labrum strongly

V-shaped, with fine teeth on cutting edge. Cirrus I with rami unequal, inner ramus oval (12-segmented), outer ramus long, slender (18-segmented) (Fig. 18E); cirri II–VI similar in morphology, rami almost equal length, outer and inner rami 25–36-segmented (Fig. 18F); caudal appendages short, 5–6 segmented (Fig. 18G).

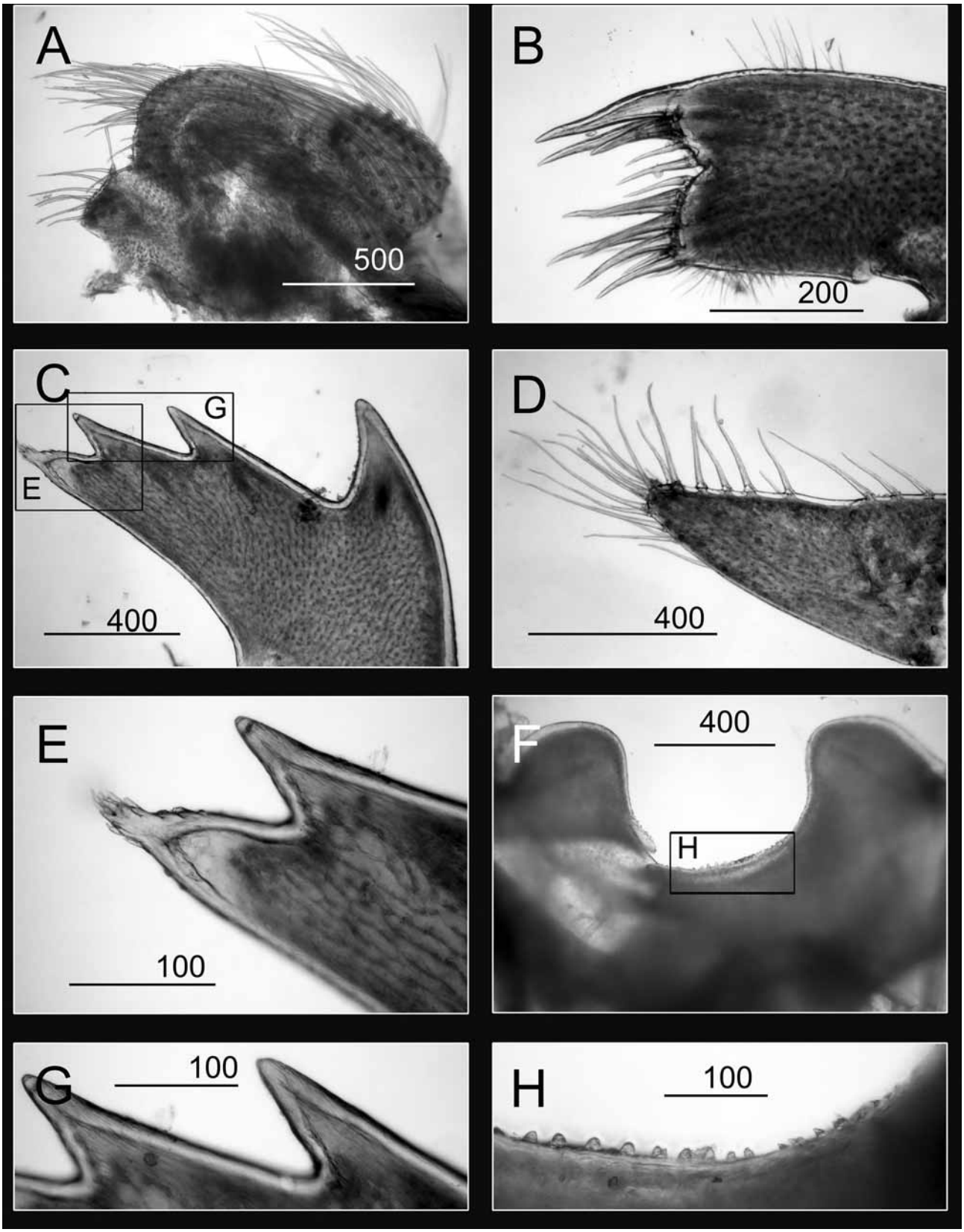

FIGURE 16. *Litoscalpellum spinosus* **sp. nov.** A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Lower margin of mandible, F. Labrum, G. Second and third teeth of mandible, H. Cutting edge of labrum. Scale bars in μm.

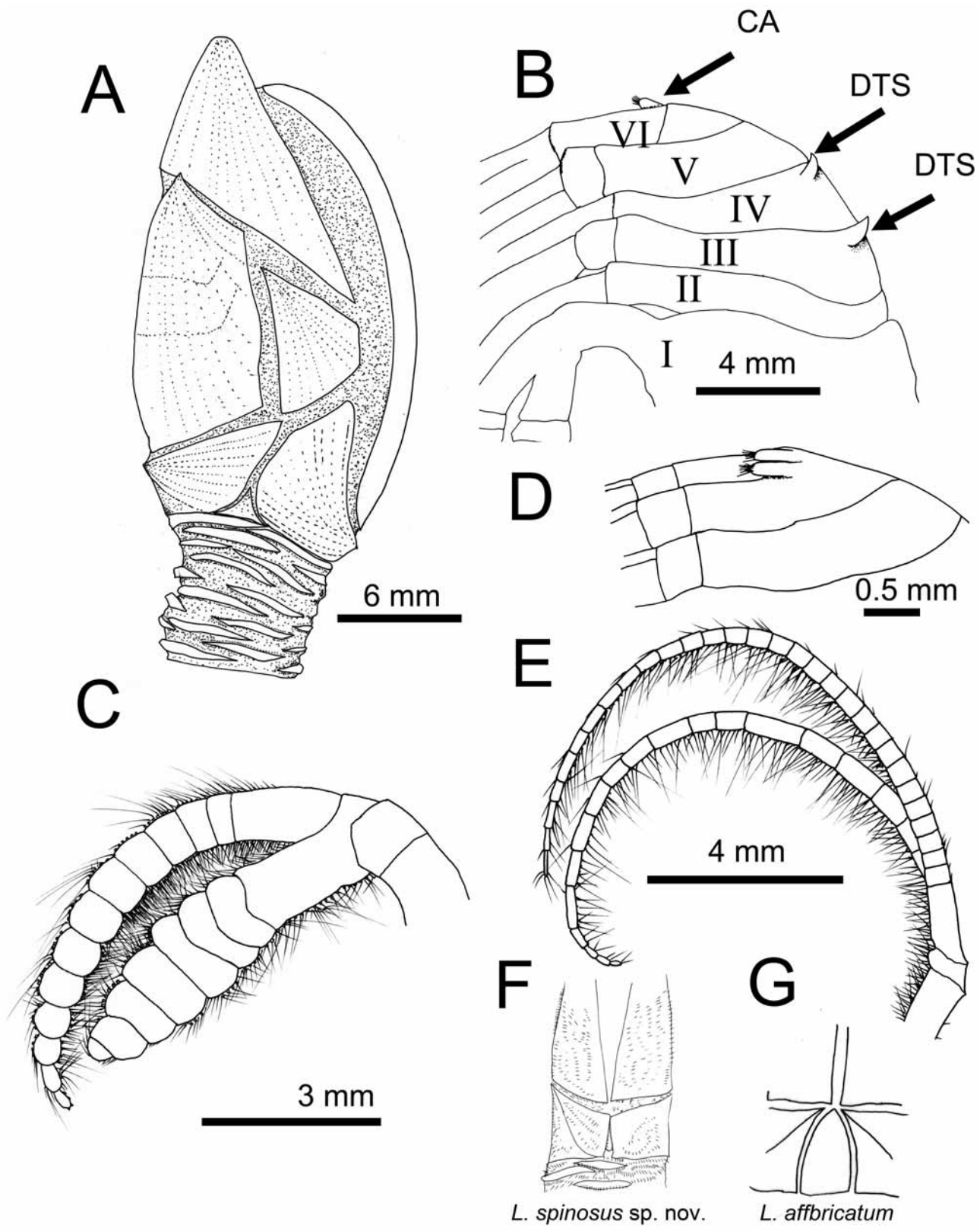

FIGURE 17. *Litoscalpellum spinosus* **sp. nov.** A. Side view of the capitulum, B. Somatic body showing the dorsal thoracic sharp processes (DTS) and caudal appendage (CA). Roman numbers indicate the cirrus number. C. Cirrus I, D. Caudal appendages, E. Cirrus II, F. Rostrum of *L. spinosus* **sp. nov.**, G. Rostrum of. *L. affbricatum* (redrawn from Foster, 1978). Scale bars in mm.

Distribution. Indo-Pacific waters including Taiwan.

Remarks. The Nan Fang Ao fishing market is a local deep-sea fishery market in Taiwan, selling fishery catches collected daily by the fishermen operating in the deep-sea in the eastern Taiwanese waters. The sample collected in the Nan Fang Ao fish market was found among the local catches from the fishermen.

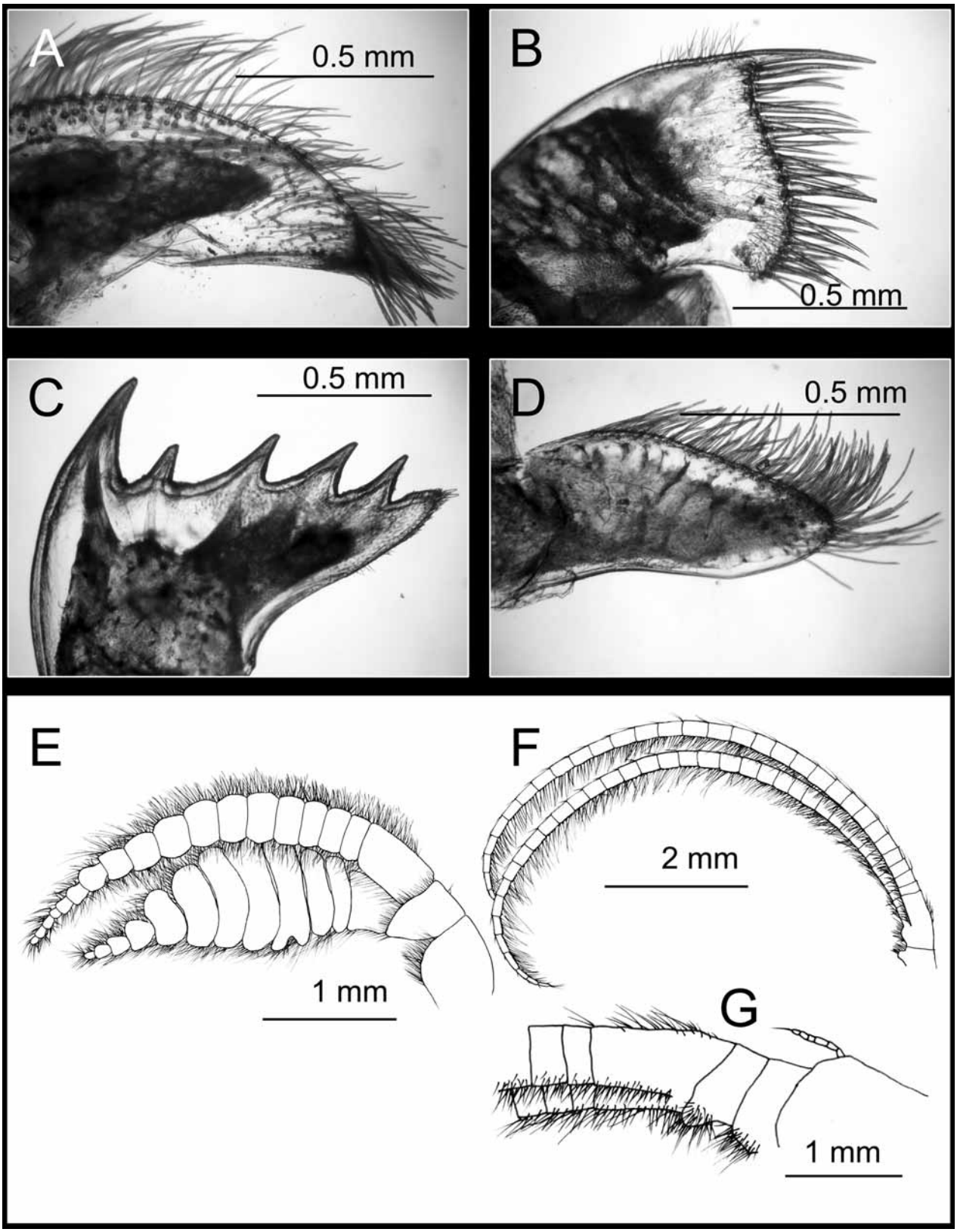

FIGURE 18. *Scalpellum stearnsii*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Cirrus I, F. Cirrus VI, G. Caudal appendage.

Order Sessilia Lamarck, 1818

Suborder Verrucomorpha Pilsbry, 1916

Family Verrucidae Darwin, 1854

***Altiverruca* Pilsbry, 1916**

***Altiverruca longimandible* sp. nov.**
Figures 2D, 19, 20

Material examined. Holotype: ASIZCR 000224, 1 specimen, Stn. CP375 (24º16.240'N, 122º11.720'E, 27 Aug. 2006, depth: 2216–2497 m), BD 9.78 mm. Paratype: NMNS-6006-003, 2 specimens, locality same as holotype, BD 8.2–9.8 mm.

Diagnosis. *Altiverruca* with single interlock between rostrum and carina, movable tergum interlocking with movable scutum by 3 main ribs; lower margin of mandible long, smooth, naked; caudal appendage long, 1/2 length of cirrus VI.

Description. Shell white, some individuals covered by dark brown coating (Figs 2D, 20A); apices of rostrum and carina marginal, produced, curved outwards (Figs 2D, 20A); rostrum and carina interlocking by 1 major rib; rostrum without secondary ridges directed towards tergal base (Figs 2D, 20A); movable tergum quadrangular, interlocking with movable scutum by 3 main ribs; movable scutum triangular (Figs 2D, 20A). Maxilla bilobed, dense, shorter setae clustered on lobes, long setae along superior margin (Fig. 19A); maxillule with wide notch, basal region of cutting edge expanded (Fig. 19B); 2 large, robust, cuspidate setae above notch, ~ 10 fine, cuspidate setae in notch, 8 large, cuspidate setae below notch (Fig. 19B); mandible elongated, with 3 teeth, equally spaced, lower margin very long, smooth, naked, inferior angle blunt, minutely pectinated (Figs 19C, E); mandibular palp elongated, setae along superior margin (Fig. 19D); labrum not concave, cutting edge straight, with numerous fine teeth (Fig. 19F). Cirrus I with rami unequal, outer ramus antenniform, 24-segmented, inner ramus short, 10-segmented (Fig. 20B); cirrus II with rami unequal, outer ramus antenniform, 21-segmented, inner ramus short, 10-segmented, with dense setae (Fig. 20C); cirri III–VI similar, rami subequal, long, slender; cirrus III with outer ramus 28-segmented, inner ramus 22-segmented; cirrus IV with outer ramus 32-segmented, inner ramus 34-segmented; cirrus V with outer ramus 27-segmented, inner ramus 30-segmented; cirrus VI with outer ramus 33-segmented, inner ramus 33-segmented (Figs 20D, E, F, G); caudal appendage long, 1/2 length of cirrus VI, 32-segmented (Fig. 20G).

Etymology. The species is named with respect to the long, lower margin of the mandible. The name of this species is treated as a noun in apposition.

Distribution. Presently known only from the type locality.

Remarks. In the present study, *Altiverruca longimandible* **sp. nov.** was recorded in the eastern waters of Taiwan. From external shell morphology, *Altiverruca longimandible* **sp. nov.** is similar to *A. navicula* (Hoek, 1913) in having the apices of the rostrum and carina produced, the rostrum and carina interlocking with 1 rib and the movable scutum and tergum interlocking by several strong ribs. The mandible of *A. longimandible* **sp. nov.**, however, has a very long, smooth, fragile lower margin that is devoid of setae, terminating at the blunt inferior angle, whilst that of *A. navicula* has a pectinated lower margin. Buckeridge (1994, 1997) reported that variation in mandible morphology may occur in *A. navicula*. In the present study, dissection of three specimens of *A. longimandible* **sp. nov.** revealed similar mandible morphology, suggesting that morphological variation of the mandible is not obvious in this species.

The mandible of *Altiverruca vitrea* Zevina, 1988 has a relatively long lower margin compared to other species, but it bears two teeth, whereas *Altiverruca longimandible* **sp. nov.** has three. No other barnacles have been reported to have such an exceptionally long lower margin (Zevina, 1987, 1988, 1993; Buckeridge, 1994; Young, 1998, 2002) and, therefore, this species is considered new to science.

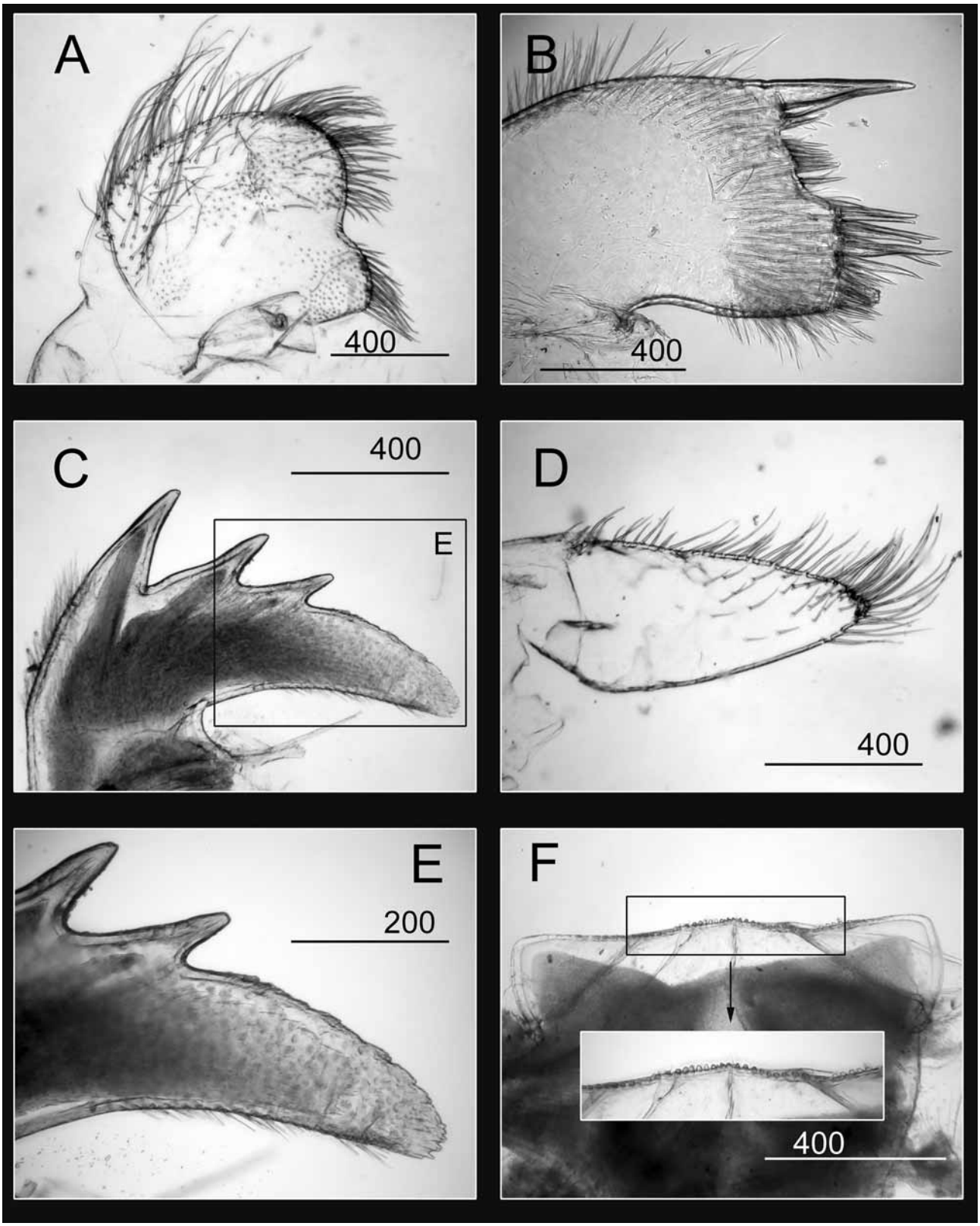

FIGURE 19. *Altiverruca longimandible* **sp. nov.** A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Lower margin of mandible, F. Labrum, insert showing fine teeth at cutting edge. Scale bars in μm.

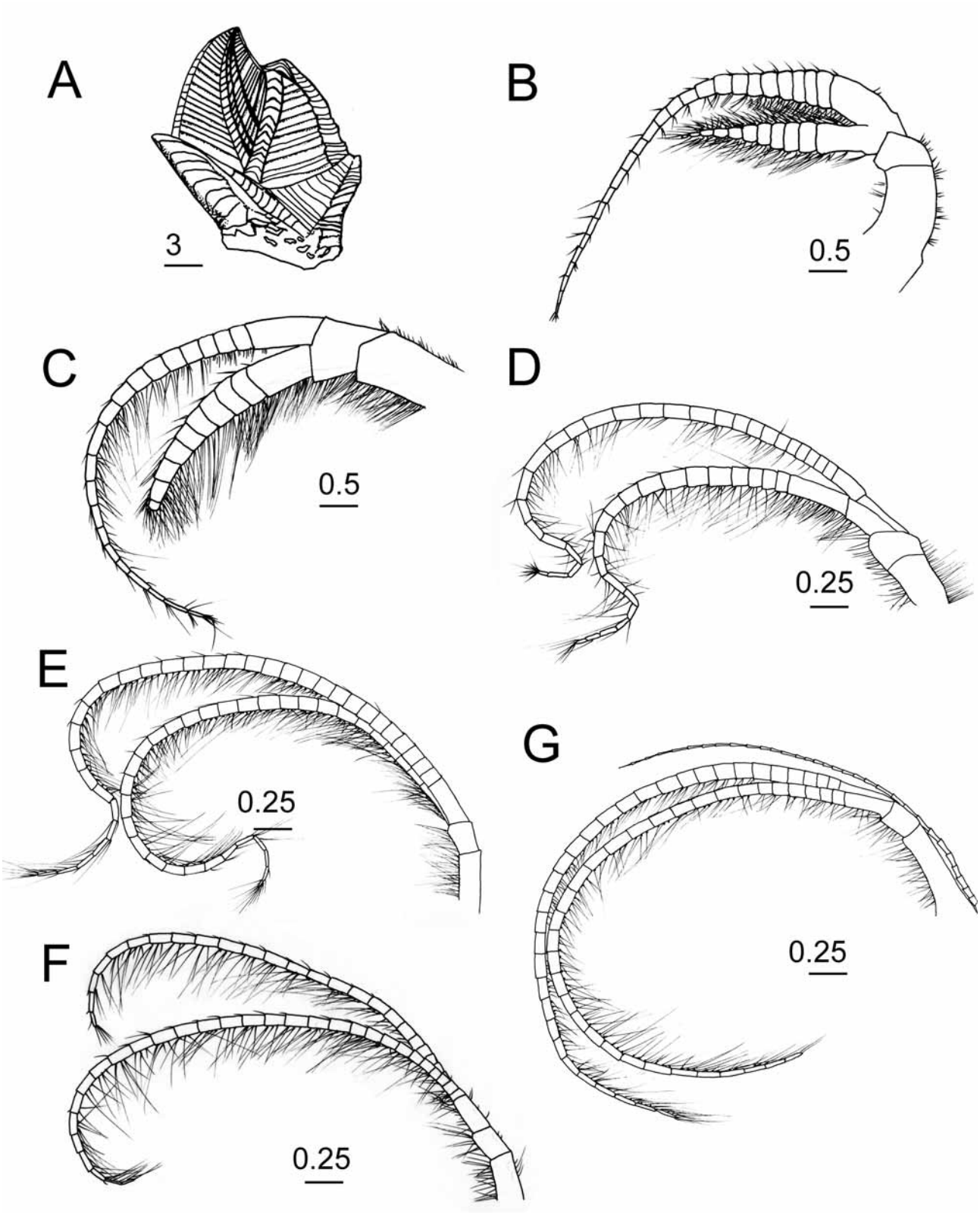

FIGURE 20. *Altiverruca longimandible* **sp. nov.** A. External view of the whole specimen, B. Cirrus I, C. Cirrus II, D. Cirrus III, E. Cirrus IV, F. Cirrus V, G. Cirrus VI, showing caudal appendage. Scale bars in mm.

***Altiverruca navicula* (Hoek, 1913)**
Figures 2E, 21, 22

Verruca navicula Hoek, 1913: 134, figs 4–6. — Nilsson-Cantell, 1927: 778, figs a–f.
Altiverruca navicula. — Buckeridge, 1994: 100, fig. 5.

Material examined. NMNS 005087-00077, 1 specimen, Stn. CP285 (24º16.09'N, 122º11.52'E, 16 Jun. 2005, depth 2268–2426 m), BD 11.37 mm.

Diagnosis. Rostral and carinal apices marginal; myophore absent from fixed scutum; operculum nearly vertical to base; movable scutum and movable tergum interlocking with 4 ribs, caudal appendages long.

Description. Shell white, rostral and carinal apices marginal, carina and rostrum interlocking in a single rib; movable tergum quadrangular, scutal margin with 5 ribs, apex curved; movable scutum triangular, tergal margin with 4 ribs, apex curved (Fig. 2E). Maxilla bilobed, with dense setae, sparse setae along superior margin (Fig. 21A); maxillule with strong, wide notch on cutting edge, 2 large cuspidate setae above notch, dense setae in notch, 7 setae below notch (Fig. 21B); mandible with 3 teeth (Fig. 21C), lower margin long, with > 8 small, cuspidate setae, inferior angle pectinate, with cuspidate setae at angle (Fig. 21E); mandibular palp elongated, dense setae along superior margin (Fig. 21D); labrum slightly concave, fine, bi-dentate to quadridentate teeth on cutting margin (Fig. 21H). Cirrus I with rami unequal, outer ramus elongated, 27-segmented, inner ramus shorter, 15-segmented (Fig. 22A); cirrus II with rami unequal, outer ramus 27-segmented, inner ramus 11-segmented (Fig. 22B); cirrus III with outer ramus 30-segmented, inner ramus 27-segmented (Fig. 22C); cirrus VI with outer ramus 36-segmented, inner ramus 37-segmented (Fig. 22D); caudal appendage long, 34-segmented (Fig. 22D).

Distribution. Pacific Ocean

Remarks. This is a new record for Taiwanese waters.

Genus *Metaverruca* Pilsbry, 1916

***Metaverruca defayeae* Buckeridge, 1994**
Figures 2F, 23, 24

Metaverruca defayeae Buckeridge, 1994: 109, fig. 9. — Buckeridge, 1997: 138.

Material examined. CEL-BB-100, 4 specimens, Stn. CP371 (24º28.521'N, 122º12.821'E, 26 Aug. 2006, depth: 582–613 m), BD 10.22–13.10 mm.

Diagnosis. External shell smooth, with dense growth lines; movable tergum and scutum with 4 articular ribs; mandible with 5 teeth; caudal appendage short, < length of basal segment of pedicle of cirrus VI.

Description. Shell white, low conic, sides steep, surface smooth, with dense growth lines; basis membranous (Fig. 2F); operculum sub-parallel to basis (Fig. 2F); orifice D-shaped (Fig. 2F); rostrum and carina articulated with up to 5 ribs (Fig. 2F); fixed scutum with myophore; movable tergum quadrangular, strong apical basal rib and secondary 3 ribs interlocking with movable scutum; movable scutum triangular, articulating with movable tergum by 3 secondary ribs and 1 apico-basal rib. Maxilla bilobed, with dense setae (Fig. 23A); maxillule notched, 2 large, cuspidate setae above notch, 6 cuspidate setae in notch, > 10 cuspidate setae below notch on expanded margin (Fig. 23B); mandible with 4 main teeth, 2 small teeth representing fifth (Figs 23C, G, E), lower margin hirsute, sharp spines and pectinations at inferior angle (Fig. 23E); mandibular palps elongated, setae along superior margin (Fig. 23D); labrum concave, with row of fine, small teeth (Figs 23F, H). Cirrus I with rami unequal, outer ramus 21-segmented, inner ramus 12-segmented (Fig. 24A); cirrus II with outer ramus longer, 19-segmented, inner ramus shorter, 13-segmented (Fig. 24B); cirri III–VI similar; cirrus III with outer ramus 23-segmented, inner ramus 22-segmented; cirrus IV with outer ramus 27-segmented, inner ramus 28-segmented; cirrus VI with outer ramus 32-segmented, inner ramus 28-segmented (Fig. 24C, D, E); caudal appendages short, 8-segmented, length < height of basal segment of pedicel of cirrus VI (Fig. 24F).

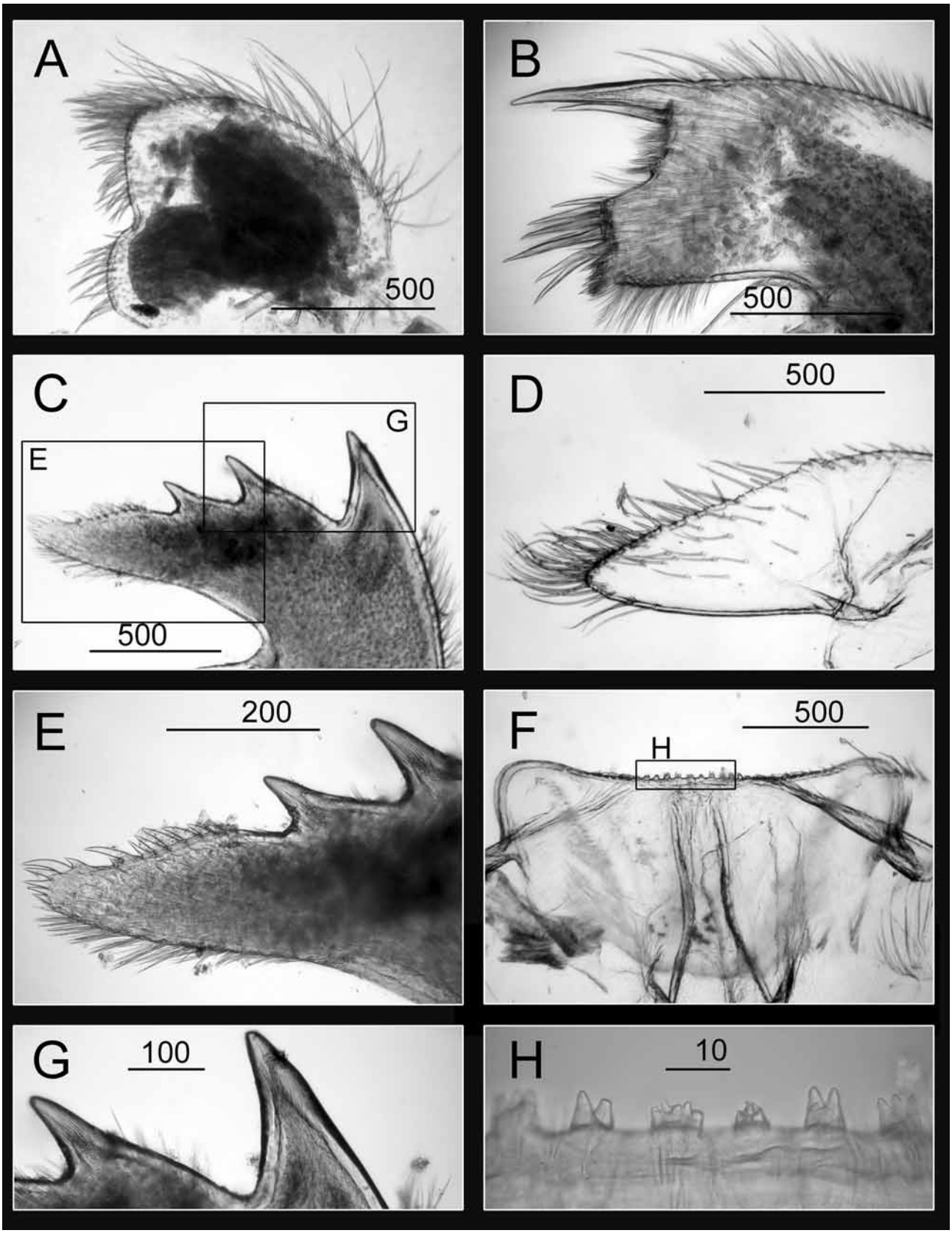

FIGURE 21. *Altiverruca navicula*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Lower margin of mandible, F. Labrum, G. First and second teeth of mandible, H. Cutting edge of mandible, showing fine teeth. Scale bars in μm.

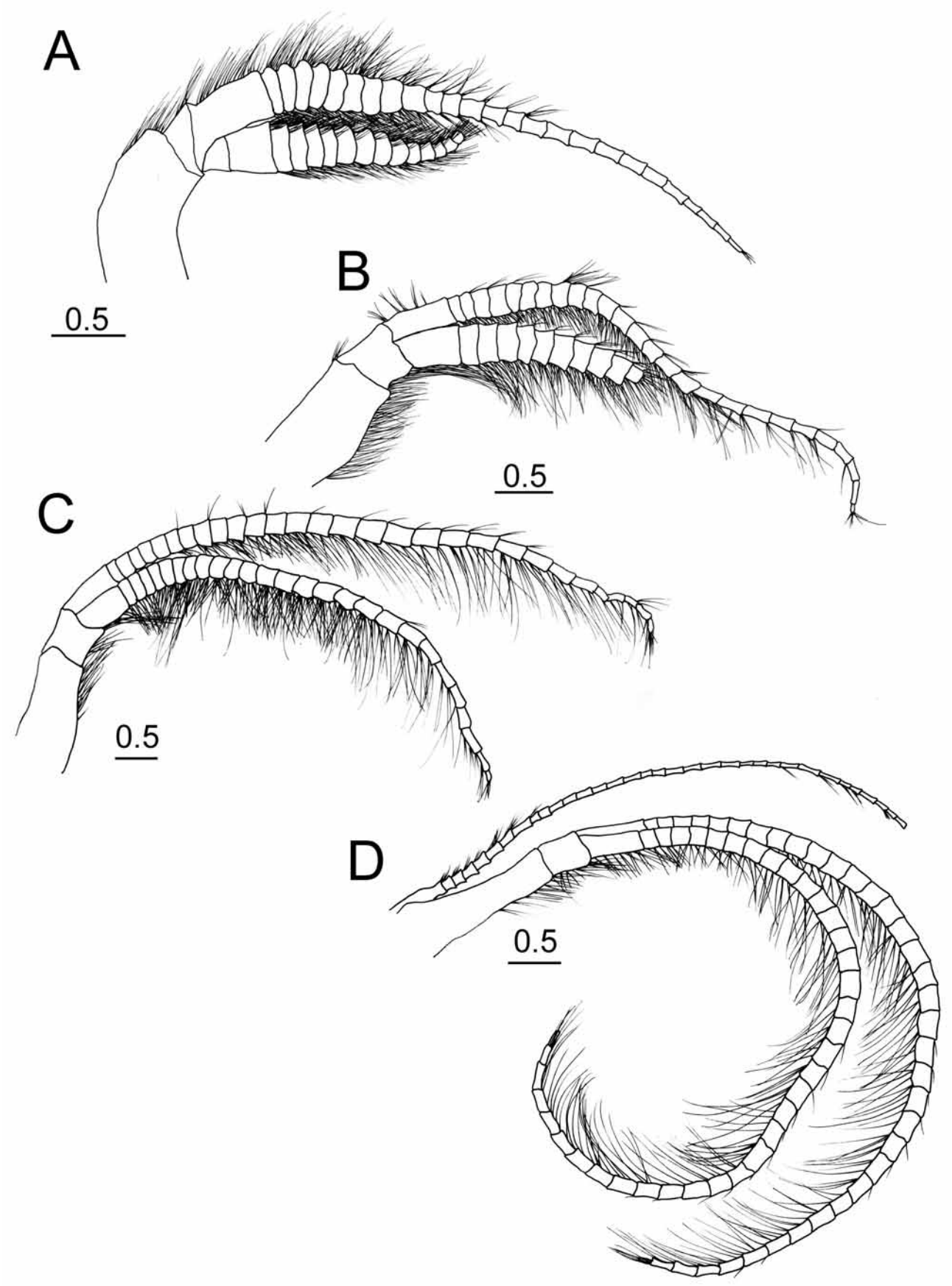

FIGURE 22. *Altiverruca navicula*. A. Cirrus I, B. Cirrus II, C. Cirrus III, D. Cirrus VI, showing caudal appendage. Scale bars in mm.

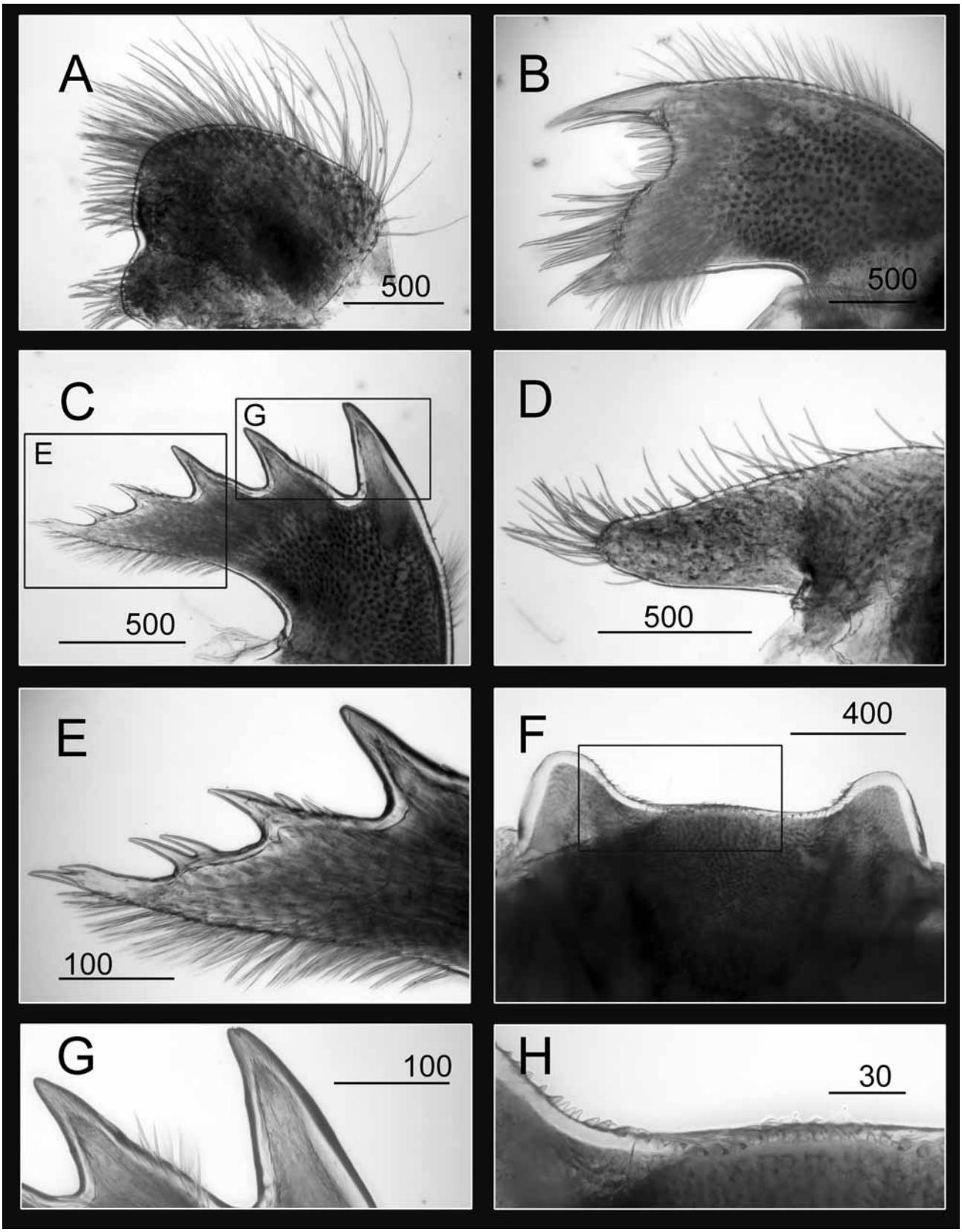

FIGURE 23. *Metaverruca defayeae*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Lower margin of mandible, F. Labrum, G. First and second teeth of mandible, H. Cutting edge of mandible, showing fine teeth. Scale bars in μm.

Remarks. This is a new record for Taiwanese waters. Buckeridge (1994) concluded *Metaverruca defayaea* to be morphologically close to *M. recta* (Aurivillius, 1898). The major difference between these two species is the number of interlocking ribs on the movable scutum and tergum; *M. defayaea* has 4 whilst *M. recta* has 3. In the present study, the fifth tooth of the mandible of *M. defayaea* is represented by 2 small teeth, whilst the fifth of *M. defayaea* in Buckeridge (1994) is represented by a single small tooth. The taxonomic status of *M. defayaea* in Taiwanese waters will need to be further evaluated from larger samples sizes and with support from a molecular approach.

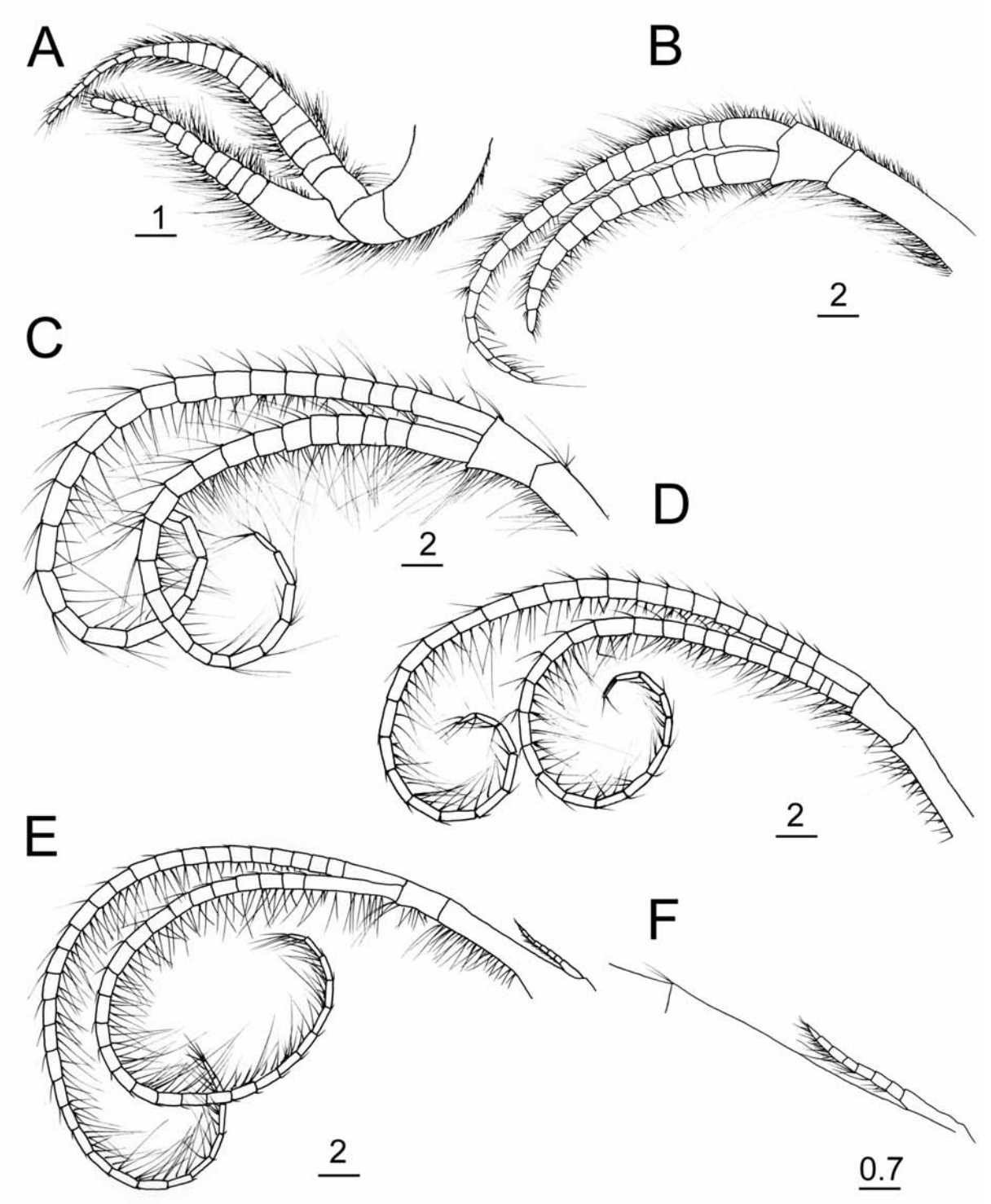

FIGURE 24. *Metaverruca defayeae*. A. Cirrus I, B. Cirrus II, C. Cirrus III, D. Cirrus IV, E. Cirrus VI, showing caudal appendage, F. Caudal appendage. Scale bars in mm.

***Metaverruca recta* (Aurivillius, 1898)**
Figures 2G, 25, 26

Verruca recta Aurivillius, 1898: 195.
Verruca sculpta Aurivillius, 1898: 197.
Verruca halotheca Pilsbry, 1916: 188, pl. 12 figs 9, 10.
Verruca cookei. — Rosell, 1989: 299, pl. 11 figs r, s, u, v (non *Verruca cookei* Pilsbry, 1927). — Rosell, 1991: 33 (non *Verruca cookei* Pilsbry, 1927).
Metaverruca recta. — Buckeridge, 1994: 116, figs 13a–f. — Young, 1998: 52.

Material examined. NMNS 20050614, 1 specimen, Stn. CP278 (24º23.63'N, 122º14.13'E, 14 Jun. 2005, depth: 1222–1239 m), BD 9.44 mm.

Diagnosis. External shell smooth, growth lines widely spaced; orifice D-shaped; movable tergum and scutum with 3 articular ribs; fixed scutum with myophore.

Description. Shell white, smooth, low conic, with operculum sub-parallel to base, growth lines widely spaced, orifice D-shaped; rostral and carinal apices marginal, movable tergum and scutum with 3 articular ribs (Fig. 2G). Maxilla bilobed, dense setae in 3 main clusters (Fig. 25A); maxillule notched, 2 large cuspidate setae above notch, 7 fine setae in notch, 7 large setae below notch on expanded margin (Fig. 25B); mandible with 3 teeth (Fig. 25C, G), lower margin with several small teeth or large pectinations, inferior angle terminating in several cuspidate setae (Fig. 25E); labrum cutting edge with sharp, fine teeth (Fig. 25F, H). Cirrus I with rami subequal, outer ramus 13-segmented, inner ramus 12-segmented (Fig. 26A); cirrus II with rami subequal, outer ramus 11-segmented, inner ramus 8-segmented (Fig. 26B); caudal appendage short, 7-segmented, length within basal length of basal segment of cirrus VI (Fig. 26C).

Distribution. Caledonia, the Philippines, Taiwan, Atlantic Ocean,

Remarks. *Metaverruca recta* is one of the largest verrucids. This is a new record for Taiwanese waters.

Genus *Rostratoverruca* Broch, 1922

***Rostratoverruca krugeri* (Broch, 1922)**
Figures 2H, 27, 28

Verruca krügeri Broch, 1922: 295, figs 43–44.
Verruca (Rostratoverruca) krügeri Broch, 1931: 46.
Rostratoverruca koehleri. — Liu & Ren, 2007: 273, fig. 119 (non *R. koehleri* (Gruvel, 1907)).

Material examined. NMNS 0003328-00076, 55 specimens, benthic trawl at Donggang, on spines of the sea urchin *Stylocidaris renei* (17 Jan. 2000), BD 2.25–6.45 mm.

Diagnosis. Operculum parallel to basis; rostrum patelliform, apex of rostrum removed from opercular margin; fixed scutum without myophore; movable tergum and scutum with 4 articular ribs; rostrum and carina with prominent rounded ribbing.

Description. Shell white, basis membranous; rostrum patelliform, apex removed from opercular margin; carina with apex produced, extending beyond basitergal angle of tergum; carina and rostrum with prominent rounded ribbing, interlocking with 3 ribs (Fig. 2H); movable scutum triangular, apex produced, incurved, 4 ribs on tergal margin, 3 ribs in occludent region, interlocking with rostrum at scutal basal margin; (Fig. 2H); movable tergum quadrangular; apex produced, incurved towards movable scutum, 3 secondary ribs interlocking with movable scutum, 3 ribs on occludent margin interlocking with carina. Maxilla globular, dense setae on margin (Fig. 27A); maxillule notched, 2 large and 2 small cuspidate setae above notch, several fine setae in notch, ~ 10 setae below notch (Fig. 27B); mandible with 3 teeth (Fig. 27C, G), lower margin strongly pectinated with sharp teeth, inferior angle ending in 4 cuspidate setae (Fig. 27E); mandibular palp subtriangular, with setae on superior margin (Fig. 27D); labrum not strongly concave, fine teeth on cutting edge, some bidentate (Fig. 27H). Cirrus I with rami subequal, outer ramus 14-segmented, inner ramus 10-

segmented (Fig. 28A); cirrus II with rami subequal, outer ramus 15-segmented, inner ramus 11-segmented (Fig. 28B); caudal appendage long, 1/2 length of cirrus VI, 18-segmented (Fig. 28C).

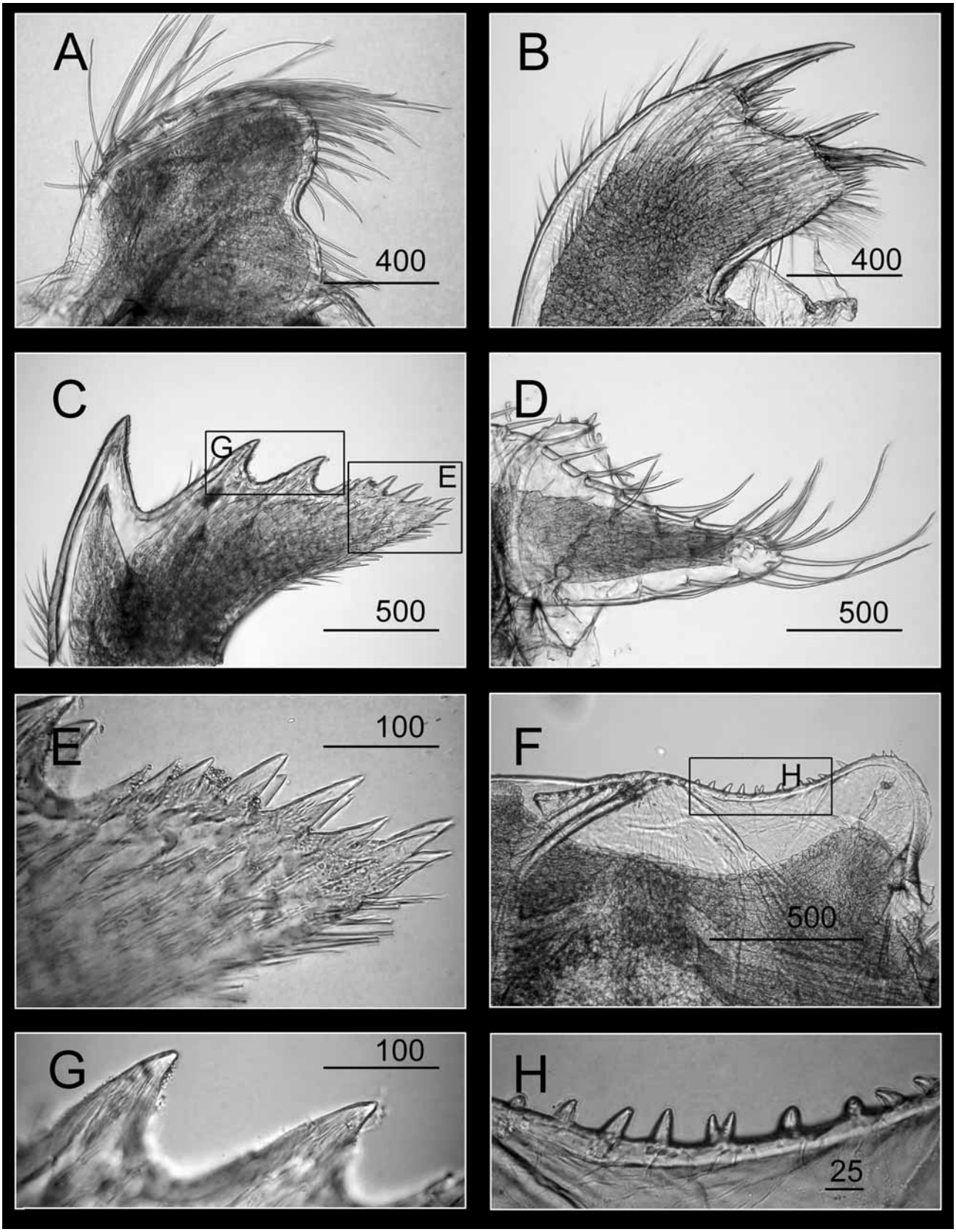

FIGURE 25. *Metaverruca recta*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Lower margin of mandible, F. Labrum, G. Second and third teeth of mandible, H. Cutting edge of mandible, showing fine teeth. Scale bars in μm.

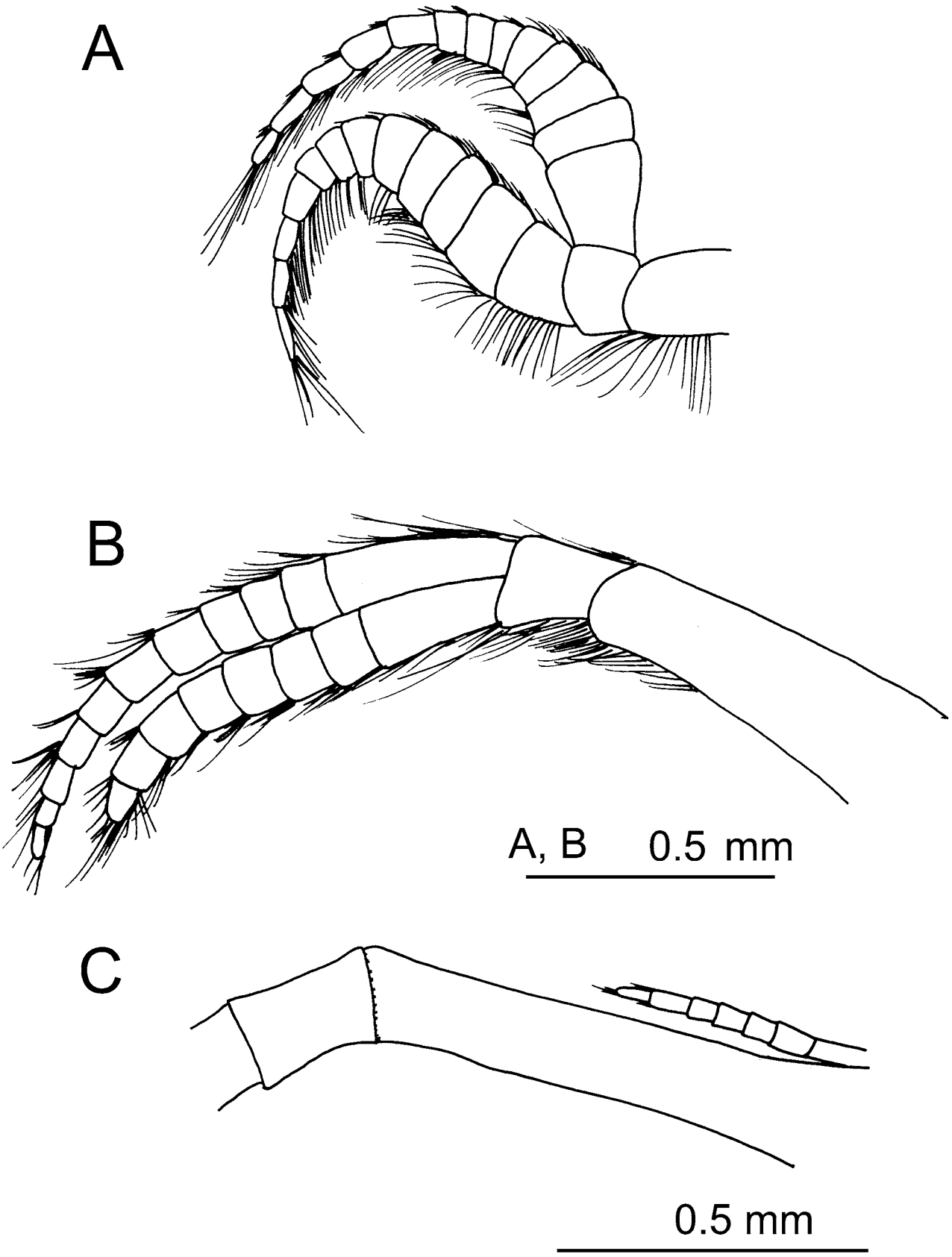

FIGURE 26. *Metaverruca recta*. A. Cirrus I, B. Cirrus II, C. Caudal appendage.

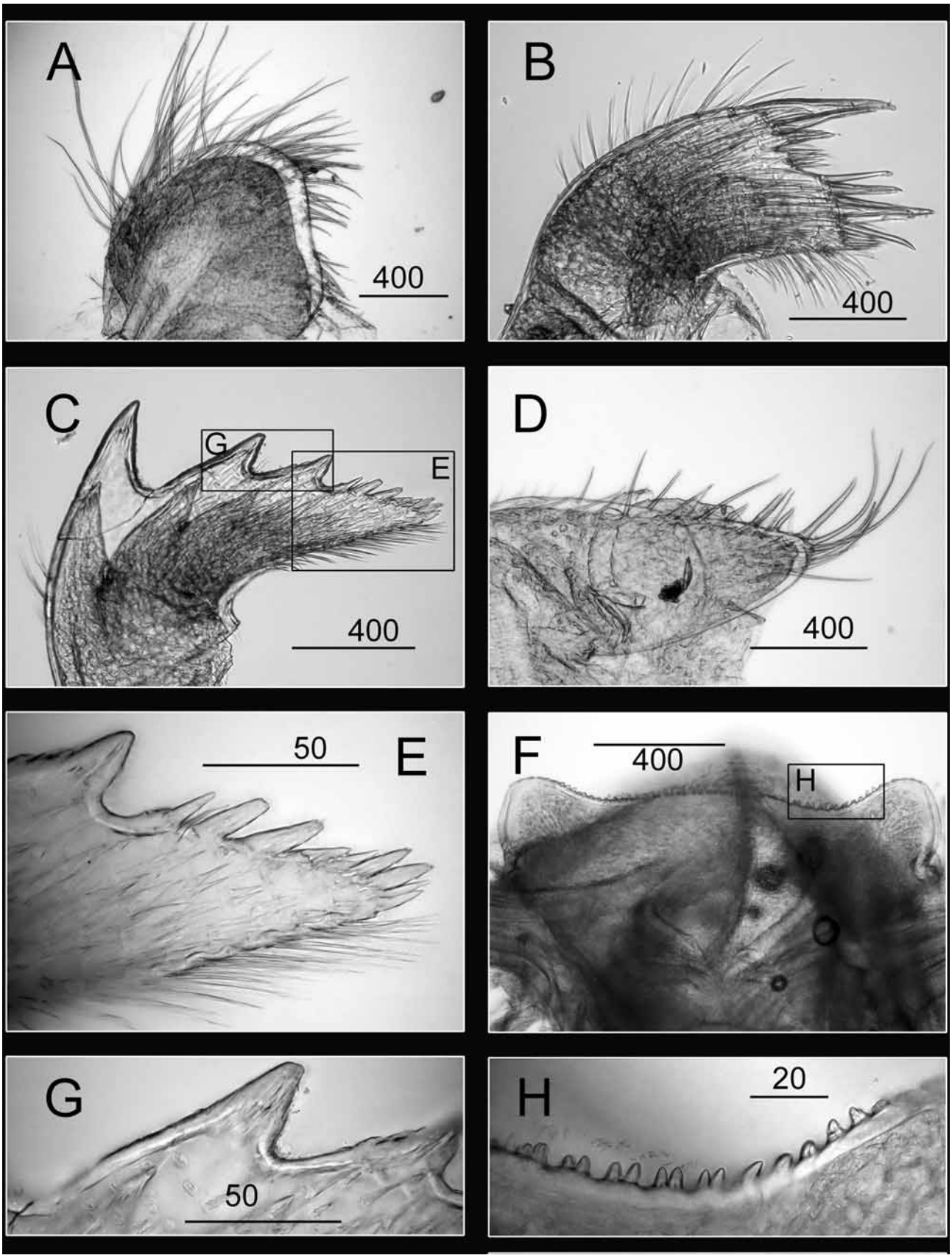

FIGURE 27. *Rostratoverruca krugeri*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Lower margin of mandible, F. Labrum, G. Second teeth of mandible, H. Cutting edge of mandible, showing fine teeth . Scale bars in µm.

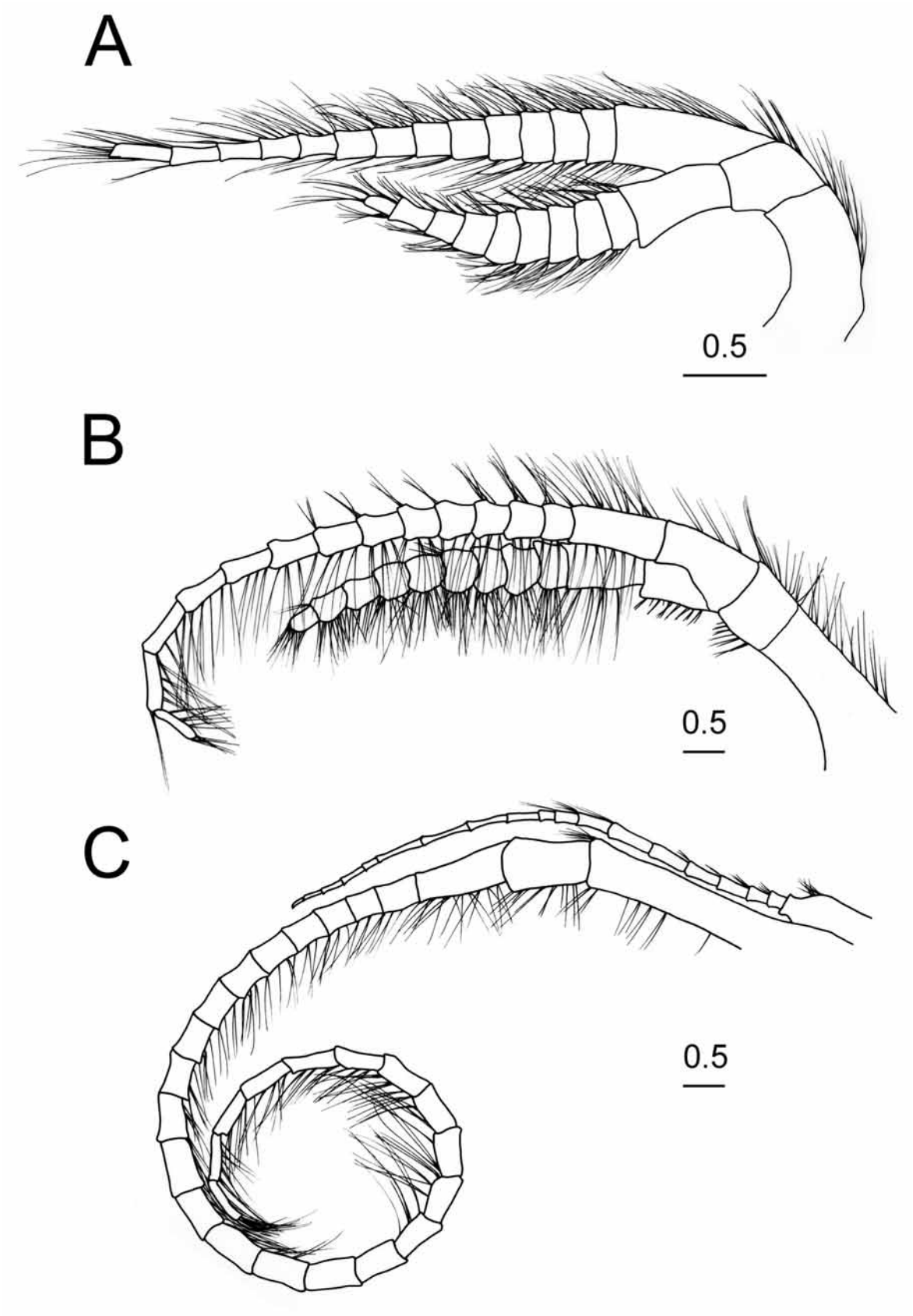

FIGURE 28. *Rostratoverruca krugeri*. A. Cirrus I, B. Cirrus II, C. Cirrus VI, showing caudal appendage. For clarity, only the inner ramus of cirrus VI was illustrated. Scale bars in mm.

Distribution. East China Sea, South China Sea, Taiwan, western Pacific.

Remarks. This is a new record for Taiwanese waters. The species has often been reported attached to the spines of sea urchins, suggesting a commensal relationship. Buckeridge (1994) concluded *Rostratoverruca koehleri* (Gruvel, 1907) was morphologically close to *R. krugeri* (Broch, 1922). When compared to *R. koehleri*, the fixed tergum of *R. krugeri* has a more prominent apex and there is more ribbing on the movable plates. Liu & Ren (2007), however, consider *R. krugeri* to be a subjective synonym of *R. koehleri*. In the present study, we consider *R. krugeri* and *R. koehleri* to be separate species and the illustration in Liu & Ren (2007) suggested their specimen is *R. krugeri*.

Suborder Balanomorpha Pilsbry, 1916

Superfamily Pachylasmatoidea Buckeridge, 1983

Family Pachylasmatidae Utinomi, 1968 (emend.)

Genus *Hexelasma* Hoek, 1913

***Hexelasma velutinum* Hoek, 1913**
Figures 2I, 29, 30

Hexelasma velutinum Hoek, 1913: 246, pl. 26 figs 1–6. — Broch, 1931: 53. — Hiro, 1933: 70, pl. 3 fig. 2. — Utinomi, 1968: 30. — Newman & Ross, 1971:155. — Newman & Ross, 1976: 46. — Jones, 2000: 273, fig. 64, tabs 28–31. — Liu & Ren, 2007: 328, fig. 146.

Material examined. CEL-BB-102, 1 specimen, Stn. CP371 (24º28.521'N, 122º12.821'E, 26 Aug. 2006, depth: 582–613 m), BD 13.88 mm.

Diagnosis. Shell with 6 compartmental plates; carina, carinolateral and lateral plates with alae, radii absent; rostrum with radii and alae absent; parietes solid, longitudinal ribs on inner surface absent; basis membranous; intermediate segments of cirri IV–VI bearing 2 pairs of long setae.

Description. Shell white, conical or cylindrical, operculum large; shell surface with parallel growth lines, covered by membrane with fine, short setae (Fig. 2I); 6 compartmental plates; carina, carinolateral and lateral plates with alae, radii absent; rostrum with radii and alae absent (Fig. 2I); parietes solid, longitudinal ribs on inner surface absent; basis membranous; scutum triangular, occludent margin straight, with large teeth, tergal margin straight; tergum narrow, scutal margin long, straight, basiscutal angle oblique, spur pronounced. Maxilla subtriangular (Fig. 29A), inferior and superior margins setose; maxillule with cutting edge notched, 2 long, cuspidate setae above notch, 3 fine short setae in notch, 12 fine setae below notch (Fig. 29B); mandible with 4 teeth, first separated from remainder (Figs 29C, G), lower margin smooth (Fig. 29E), inferior angle sharp (Fig. 29E); mandibular palp rectangular, apex blunt, dense setae on superior margin and distally (Fig. 29D); labrum concave, deep notch absent, cutting edge with fine bidentate and tridentate teeth (Fig. 29H). Cirrus I with rami unequal, outer ramus shorter, 11 segmented, inner ramus longer 11-segmented (Fig. 30A); cirrus II with rami subequal, outer ramus 14-segmented, inner ramus 13-segmented (Fig. 30B); cirrus III with rami subequal, outer ramus 37-segmented, inner ramus 43-segmented (Fig. 30C); intermediate segments of cirri IV–VI with 2 pairs of long setae (Fig. 30D).

Distribution. South China Sea, Japan, Taiwan and the Philippines.

Remarks. This is a new record for Taiwanese waters.

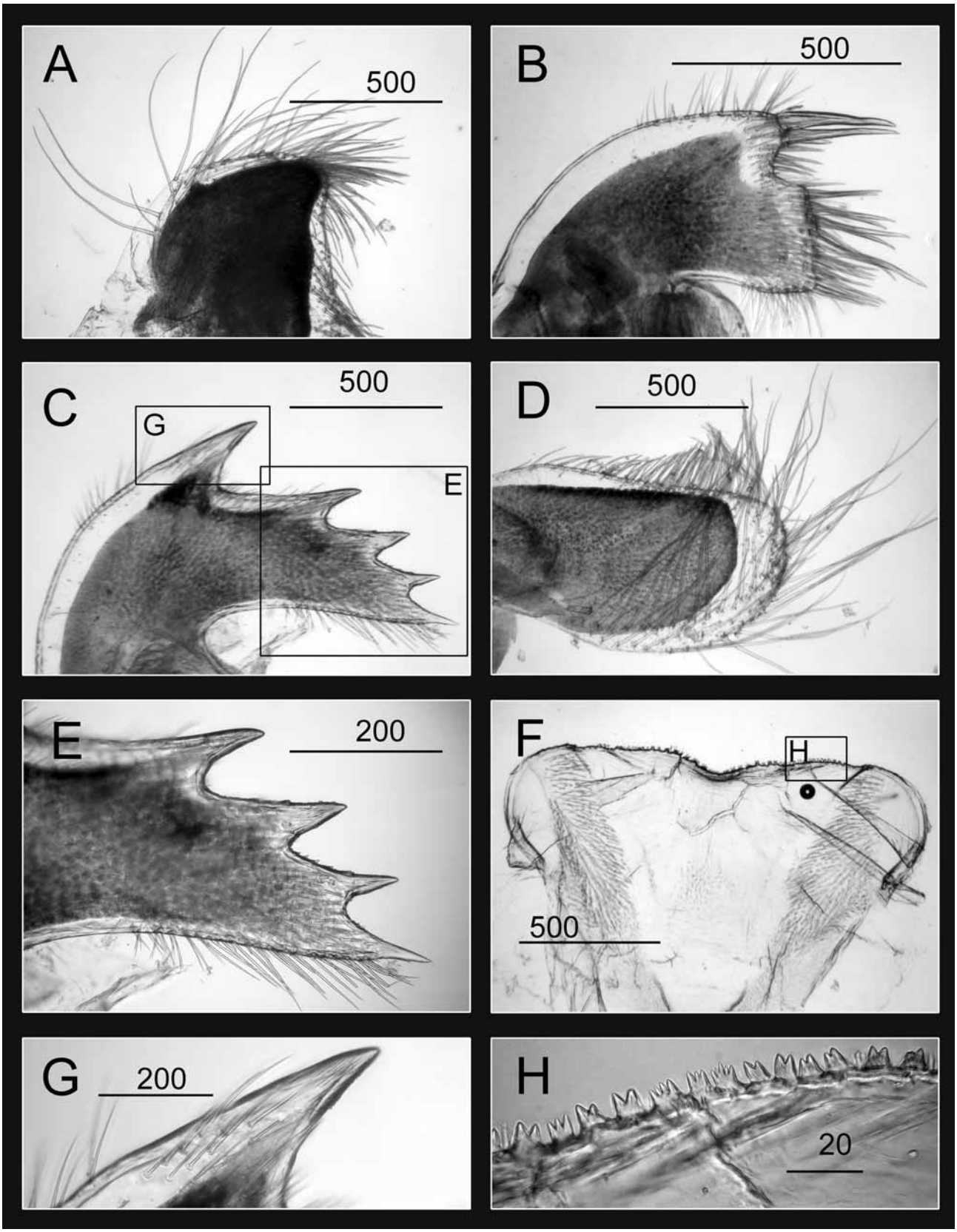

FIGURE 29. *Hexelasma velutinum*. A. Maxilla, B. Maxillule, C. Mandible, D. Mandibular palp, E. Lower margin of mandible, F. Labrum, G. First teeth of mandible, H. Cutting edge of mandible, showing fine teeth. Scale bars in µm.

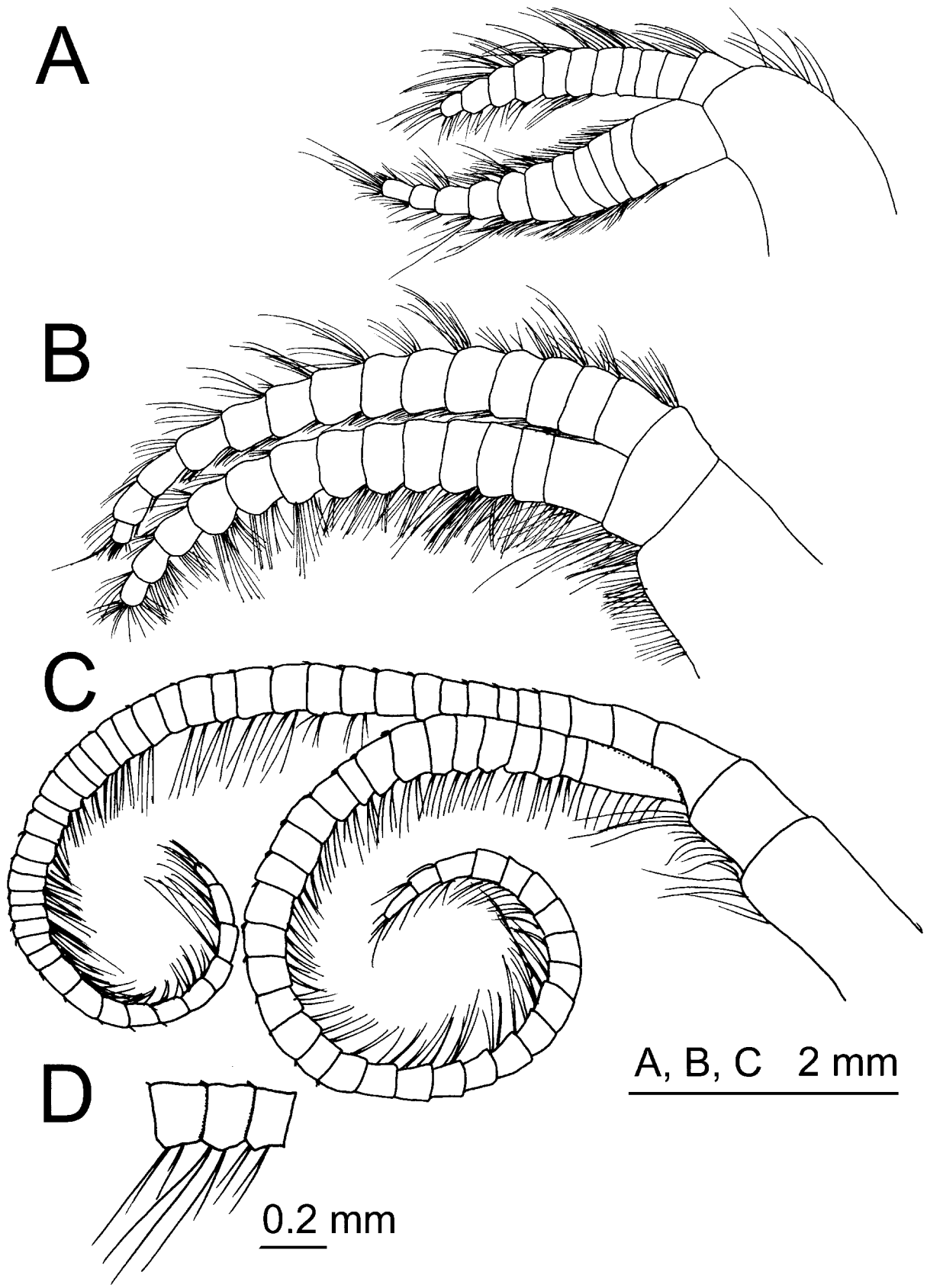

FIGURE 30. *Hexelasma velutinum.* A. Cirrus I, B. Cirrus II, C. Cirrus III, D. intermediate segments of inner ramus of cirrus VI.

Discussion

The present study reports a total of 18 species, with 17 new records including two new species of deep-sea barnacles from Taiwanese waters, suggesting that the diversity of Taiwanese deep-sea barnacles is greater than has been previously reported. In the present study, *Annandaleum japonicum*, *Trianguloscalpellum weltnerianum* and *Metaverruca defayaea* were collected from the eastern waters of Taiwan. These three species have also been recorded from the Philippine Basin (Hoek, 1883; Buckeridge, 1994), suggesting that the distribution of some deep-sea species may be associated with the topography of the ocean floor, being confined within ocean basins. Previously, there has only been one record of *Tarasovium orientale* from the East China Sea (Liu & Ren, 2007). In the present study, *T. orientale* was recorded in the Taiwan Strait. The distribution of *T. orientale* may be affected by the China Coastal Current, which passes from the East China Sea into the Taiwan Strait in the winter months (Jan et al., 2002). Some of the species collected in the present study, including *Euscalpellum rostratum*, *Scalpellum stearnsii*, *Trianguloscalpellum regium* and *Metaverruca recta*, have wide geographical distributions, being distributed in several major oceans.

The distribution of deep-sea barnacles may be attributed to the length of time taken for larval development, the pattern of deep-sea currents and the phylogeography of the deep-sea floor. Deep-sea barnacles exhibit a longer developmental time than shallow water species, for example, *Neoverruca* sp. completed the larval stages in 1.0–1.5 month at a temperature of 4°C (Watanabe et al., 2004) compared to shallow water species, for example *Tetraclita squamosa* Bruguiére, 1789 and *T. japonica* (Pilsbry, 1916) completed their larval stages at about 14 days (Chan, 2003). Such long developmental times can allow larvae to be dispersed over a great geographical distance via deep-sea currents. Dispersal can also be affected by larval behaviour. *Newmaniverruca albatrossiana* Young, 1998, an obligate on the spines of deep-sea sea urchins, has the early development of a cyprid-like antennule in the late naupliar stage for securing such specific habitats (Watanabe et al., 2008). Such an adaptation could reduce the length of time available for larval dispersal.

Research on the biogeography, biodiversity and ecology of deep-sea barnacles is still limited due to a number of difficulties, such as obtaining adequate sample sizes, scattered sample locations and the fact that most old museum collections were fixed in formalin, which makes extraction of DNA impossible. Previous studies on the biogeography of deep-sea species have been based on morphological identification and may have overlooked the presence of cryptic species. With advancement in deep-sea sampling practices, including deep-sea submersibles and more efficient trawling devices (Fujikura et al., 2008; Tsai et al., 2009), samples can now be obtained over finer spatial scales in larger quantities and can be preserved in ethanol for potential molecular studies. Such advancements will allow the development of research in genetic differentiation, population genetics and phylogeography of deep-sea barnacles, using a combination of morphological and molecular approaches.

Acknowledgement

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