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Research article

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New species of deep-water *Calcigorgia* gorgonians (Anthozoa: Octocorallia) from the Sea of Okhotsk, with a re-diagnosis and a taxonomic review of the genus

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Abstract. This paper provides descriptions of two new species of *Calcigorgia* gorgonians collected from the Sea of Okhotsk between 1973 and 2008. The new species are *Calcigorgia herba* sp. nov. and *C. lukini* sp. nov., belonging to the deep-water coral fauna of the temperate Northern Pacific. The taxonomy structure of the genus is reviewed and a comparative table is provided for all known species of *Calcigorgia*. The following taxonomic changes are made: the diagnosis of the genus was corrected from that given in Matsumoto *et al.* (2019); synonymization of *C. simushiri* Dautova, 2018 with *C. spiculifera* Broch, 1935 and inclusion of additional specimens in *C. japonica* Dautova, 2007 (both performed by Matsumoto *et al.* 2019) are assumed erroneous. The finding of previously undescribed species emphasizes the need for further surveys, particularly in deeper waters, to improve knowledge of the Octocorallia fauna in Far East seas. The distribution of *Calcigorgia* (Octocorallia, Acanthogorgiidae) is reviewed and presented based on field and collection studies published since 1935 as well as miscellaneous data from previous literature.

Keywords. *Calcigorgia herba* sp. nov., *Calcigorgia lukini* sp. nov., taxonomy, sclerites, distribution.

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Introduction

Due to their long lifespan and slow recovery from physical damage, deep cold-water corals attract attention as important components of vulnerable marine ecosystems. Their importance includes their role as nurseries for fish larvae (Baco & Shank 2005; Roberts *et al.* 2006; Baillon *et al*. 2012; Miyamoto *et al.* 2017). Species of the order Octocorallia, like other corals, provide biogenic substrata. They can be found from tropical shallows to polar and deep-water environments, even deeper than 6000 m (Williams 2011; Zapata-Guardiola & Lopez-Gonzalez 2010). The complex three-dimensional biogenic substrata provided by cold-water Octocorallia, mostly gorgonians, support a very high level of biodiversity similar to that of coral reefs (Buhl-Mortensen & Mortensen 2004, 2005; Auster *et al.* 2005; Roberts *et al.* 2006;

Parrish & Baco 2007; Buhl-Mortensen *et al.* 2016). There are vast regions around the world where very little collecting has been done, such as the Arctic, the Sea of Okhotsk and the western part of the Bering Sea (Pérez *et al*. 2016; Dautova 2018a). One of these regions is the area around the Sakhalin Island and the Kurile Islands (Northwest Pacific), from where only a few deep-water gorgonian genera have been recorded (Broch 1935; Dautova 2012, 2018a, 2018b; Matsumoto *et al.* 2019). Among these, *Calcigorgia* Broch, 1935 was described as a new gorgonian genus (with a single species, *Calcigorgia spiculifera* Broch, 1935), based on material collected at depths of 150–165 m near the northern part of the Sakhalin Island (54°36′ N, 143°48′ E, Broch 1935). Since 2007, three more species were added to the genus: *Calcigorgia japonica* Dautova, 2007, *C. matua* Dautova, 2018 and *C. simushiri* Dautova, 2018. Later, four species were added to the genus by Matsumoto *et al.* (2019). The present paper provides new data on this genus, collected by the Russian Academy of Sciences and the Pacific Fisheries Research Center during a series of expeditions in the second half of the 20th century. Descriptions of the new species enlarge our knowledge of the distinctive taxonomic characters for the genus and provide new data on its distribution. The taxonomic importance of some characters is discussed.

Data on the distribution of the representatives of the genus are summarized based on field data and the literature.

Material and methods

The samples were collected by dredging and fixed in 70% ethanol during field expeditions of the Pacific Fisheries Research Center (PFRC) and the National Scientific Centre of Marine Biology (NSCMB, formerly Institute of Marine Biology) of the Far Eastern Branch of the Russian Academy of Sciences (1973, 1987, RV *Tikhookeansky*; 2008, RV *Akademik Oparin*). Specimens belonging to both new species are registered in the Museum of the Institute of Marine Biology, National Scientific Center of Marine Biology FEB RAS, Vladivostok, Russia (MIMB). The tissue samples of the following different colony parts were examined separately: tentacles, polyp body wall, and coenenchyme. The organic matter in the samples was removed using sodium hypochlorite. The sclerites were washed from hypochlorite with distilled water and ethanol (70%) and, after drying in air, were mounted on carbon double adhesive tape and carbon coated. Images of the sclerites were obtained with scanning electron microscopy (SEM, a Zeiss Evo 40, Far East Center of Electron Microscopy, Vladivostok, Russia) with optimal magnification for each sclerite size. The sclerite types recognized in the studied specimens are named in accordance with Bayer *et al*. 1983. Specimens of the species *Calcigorgia spiculifera*, *C. japonica*, *C. matua* and *C. simushiri*, whose sampling data are in Dautova (2018b), were used for comparison. Comparative material is stored in MIMB and in the Zoological Institute RAS in St.-Petersburg, Russia.

Repositories

MIMB = Museum of the Institute of Marine Biology, National Scientific Center of Marine Biology FEB RAS, Vladivostok, Russia

ZIN = Zoological Institute RAS, St.-Petersburg, Russia

Results

Phylum Cnidaria Verrill, 1865
Class Anthozoa Ehrenberg, 1834
Subclass Octocorallia Haeckel, 1866
Order Alcyonacea Lamouroux, 1812
Suborder Holaxonia Studer, 1887
Family Acanthogorgiidae Gray, 1859

Genus ***Calcigorgia*** Broch, 1935

Diagnosis

Acanthogorgiid gorgonians whose sclerites are not individually conspicuous and not regularly arranged in the polyp. Sclerites are spindles, capstans, ovals, and clubs with warty, leafy, or serrated heads.

Remarks

The diagnosis given above combines those provided by Broch (1935) and Bayer (1981), and adds the cases when clubs with leafy or serrated (dentate) heads are present. Leafy clubs were shown for *Calcigorgia matua*, *C. herba* sp. nov. and *C. lukini* sp. nov. Clubs with serrated heads were found in *C. japonica* and in some specimens of *Calcigorgia* from Matsumoto *et al.* (2019). Matsumoto *et al.* (2019) also gave a diagnosis of the genus, but they wrongly noted that "tentacular sclerites are scales or absent; polyp and coenenchymal sclerites in the form of stout tuberculate spindles" (Matsumoto *et al.* 2019: 2–3). *Calcigorgia spiculifera*, the type of the genus, has not only scales but also clubs and spindles in the tentacles. Its polyp body and coenenchyme with capstans and ovals (Broch 1935: 22–25, fig. 14; Table 1 of the present paper). Additionally, various sclerite types besides the scales were documented in tentacles and other parts of colonies of a range of *Calcigorgia* representatives, including those described in Matsumoto *et al.* 2019 (Table 1 of the present contribution).

Calcigorgia herba sp. nov.
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Figs 1–7; Table 1

Diagnosis

Calcigorgia colonies scantly branched, with long smooth stem. Polyps in alcohol-preserved material up to 3 mm high and up to 2 mm wide, crowded in distal parts of colonies, arranged irregularly on the surface of the colony. Polyp body wall cylindrical in shape and with smooth surface. Polyp tentacles with scales, warty rods and clubs, poorly developed clubs with leafy processes on head, spindles, capstans (8-radiate) and ovals. Polyp body walls with warty clubs, club-like warty spindles, warty spindles, poorly developed clubs with leafy processes on head, ovals, and capstans (8-radiate). Coenenchyme with capstans (8-radiate) and ovals.

Etymology

The specific epithet 'herba' is due to a shape of colonies similar to a plant with a stalk in the form of a hollow straw and with small flower-like protrusions reminiscent of ears of corn or tussocks.

Material examined

Holotype

SEA OF OKHOTSK – **Kurile Islands** • 135 × 13 mm; Matua Is.; expedition of PFRC, NSCMB, and ZIN RAS on RV *Tikhookeansky*, station 306, sample 895; 48°01′ N, 153°22′ E; depth 100 m; 18 Aug. 1987; V. Lukin leg.; dredged; MIMB 20744.

Fig. 1. *Calcigorgia herba* sp. nov. **A**. Holotype MIMB 20744, Kurile Islands, Sea of Okhotsk. **B**. Paratype MIMB 20745, Kurile Islands, Sea of Okhotsk. **C**. One specimen, Kurile Islands, Sea of Okhotsk, MIMB 20709. **D–E**. Two specimens, Kurile Islands, Sea of Okhotsk, MIMB 20748. **F**. Terminal polyps, holotype MIMB 20744. **G**. Terminal polyps, paratype MIMB 20745. Scale bars: A–E = 20 mm; F–G = 10 mm.

Paratype

SEA OF OKHOTSK – **Kurile Islands** • 159 × 9 mm; Matua Is.; expedition of PFRC, NSCMB, and ZIN RAS on RV *Tikhookeansky*, station 306, sample 895; 48°01′ N, 153°22′ E; depth 100 m; 18 Aug. 1987; V. Lukin leg.; dredged; MIMB 20745.

Additional material

SEA OF OKHOTSK – **Kurile Islands** • 1 specimen; Rikord Str.; cruise on RV *Tikhookeansky*; 47°18′ N, 152°34′ E; depth 100 m; 18 Jul. 1987; S. Grebelniy leg.; dredged; MIMB 20684 • 1 specimen; Urup Is.; station 420; 46°19′ N, 150°42′ E; depth 100 m; 12 Sept. 1973; MIMB 20688 • 1 specimen; Ketoy Is.; cruise on RV *Tikhookeansky*; 47°23′2″ N, 152°39′4″ E; depth 200 m; 18 Aug. 1987; S. Grebelniy leg.; MIMB 20694 • 1 specimen; Urup Is.; cruise on RV *Tikhookeansky*; 46°19′ N, 150º42′ E; V. Lukin leg.; MIMB 20709 • 1 specimen; Diana St., between Simushir Is. and Ketoy Is.; cruise on RV *Tikhookeansky*, station 289, sample 846; 47°15′8″ N, 152°28′1″ E; depth 75 m; 17 Aug. 1987; MIMB 20746 • 1 specimen; Rasshua Is.; cruise on RV *Tikhookeansky*, station 300, sample 877; 48°01′ N, 153°22′ E; depth 100 m; 12 Aug. 1987; MIMB 20747 • 2 specimens; Ketoy Is.; cruise on RV *Tikhookeansky*; 47°23′2″ N, 152°39′4″ E; depth 200 m; 18 Aug. 1987; S. Grebelniy leg.; MIMB 20748 • 1 specimen; Rasshua Is.; cruise on RV *Tikhookeansky*, station 300; 47°49′ N, 153°00′9″ E; depth 100 m; 19 Aug. 1987; V. Lukin leg.; MIMB 20749.

Description

Holotype

Colony scantly branched (Fig. 1A), with long smooth stem. Polyps crowded in the distal part of colony, arranged irregularly on the surface of the colony (Fig. 1F).

Colony 135 mm high and 13 mm wide (Fig. 1A). Polyps up to 3 mm high and 2 mm wide. Polyp body wall cylindrical in shape, with smooth surface; tentacles folded over polyp, partly retracted to inside (Fig. 1F).

Coenenchyme 0.5 mm thick and consists of two layers, a 0.4 mm thick outer layer, with smooth surface, and a very thin inner layer. Axis with concentric layers; no mineralization observed. Sclerites unordered in tentacles, polyp body wall and coenenchyme.

Tentacles contain small warty rods, scales, warty spindles, clubs, capstans and ovals. Warty spindles, up to 0.11 mm long (Fig. 2A). Scales, up to 0.11 mm long, flattened, with notched edges (Fig. 2B). Warty spindles, up to 0.22 mm long, with tall and asymmetrically developed processes (Fig. 2C). Warty clubs mainly 0.12–0.2 mm long, with plump warty heads and straight warty handles (Fig. 2D). Smaller clubs, up to 0.15 mm long, poorly developed (Fig. 2E). Their handles short and thick, blunt, bearing small crowded warts; the heads consist of notched leafy processes (Fig. 2E). Club-like spindles, up to 0.23 mm long, with some accumulation of processes on one end (Fig. 2F) and warts tending to be girdled. Capstans (8-radiate), usually up to 0.12–0.14 mm long, not numerous (Fig. 2G). Some well calcified capstans, up to 0.16 mm long, transitional to warty ovals. These ovals, up to 0.19 mm long, bear crowded warts tending to be conjunct (Fig. 2H).

Polyp body wall with warty clubs, mainly 0.15–0.18 mm long, with plump head consisting of warty processes (Fig. 3A). Shorter clubs, up to 0.16 mm long, poorly developed, with notched leafy processes on heads; handles of short clubs thick and covered with small warts (Fig. 3B). Longer clubs transitional to club-like spindles, up to 0.16 mm long, with some accumulation of warts on one end (Fig. 3C). Plump spindles, up to 0.21 mm long, straight, with warts tending to be girdled (Fig. 3D). Short clubs also coincide with ovals, mostly 0.14–0.16 mm long, densely covered by unordered warts (Fig. 3E),

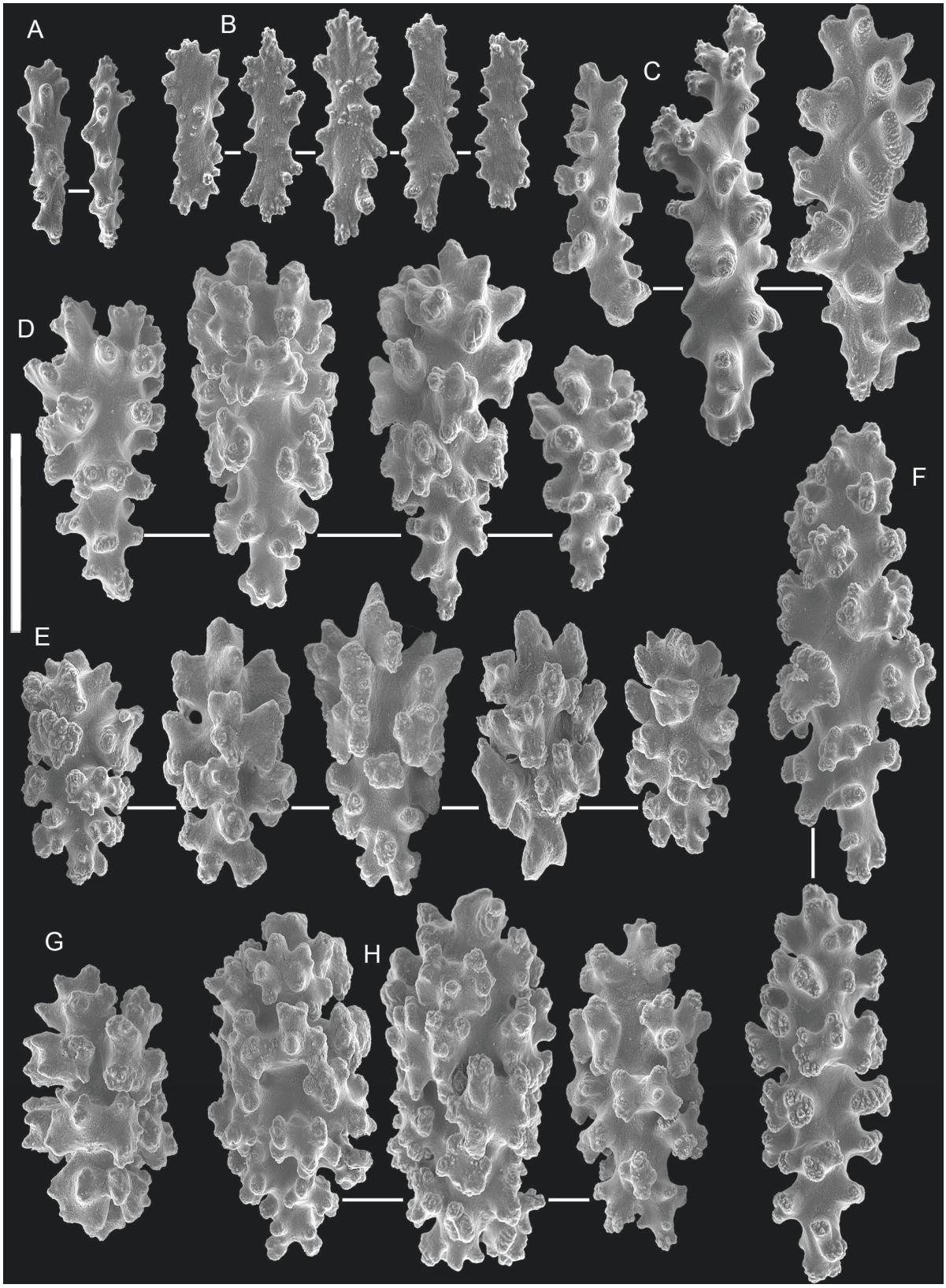

Fig. 2. *Calcigorgia herba* sp. nov., holotype MIMB 20744, sclerites from the tentacles. **A**. Rods. **B**. Scales. **C**. Warty spindles. **D**. Warty clubs. **E**. Poorly developed clubs with serrated processes. **F**. Club-like spindles. **G**. Capstan (8-radiate). **H**. Ovals. Scale bar = 0.1 mm.

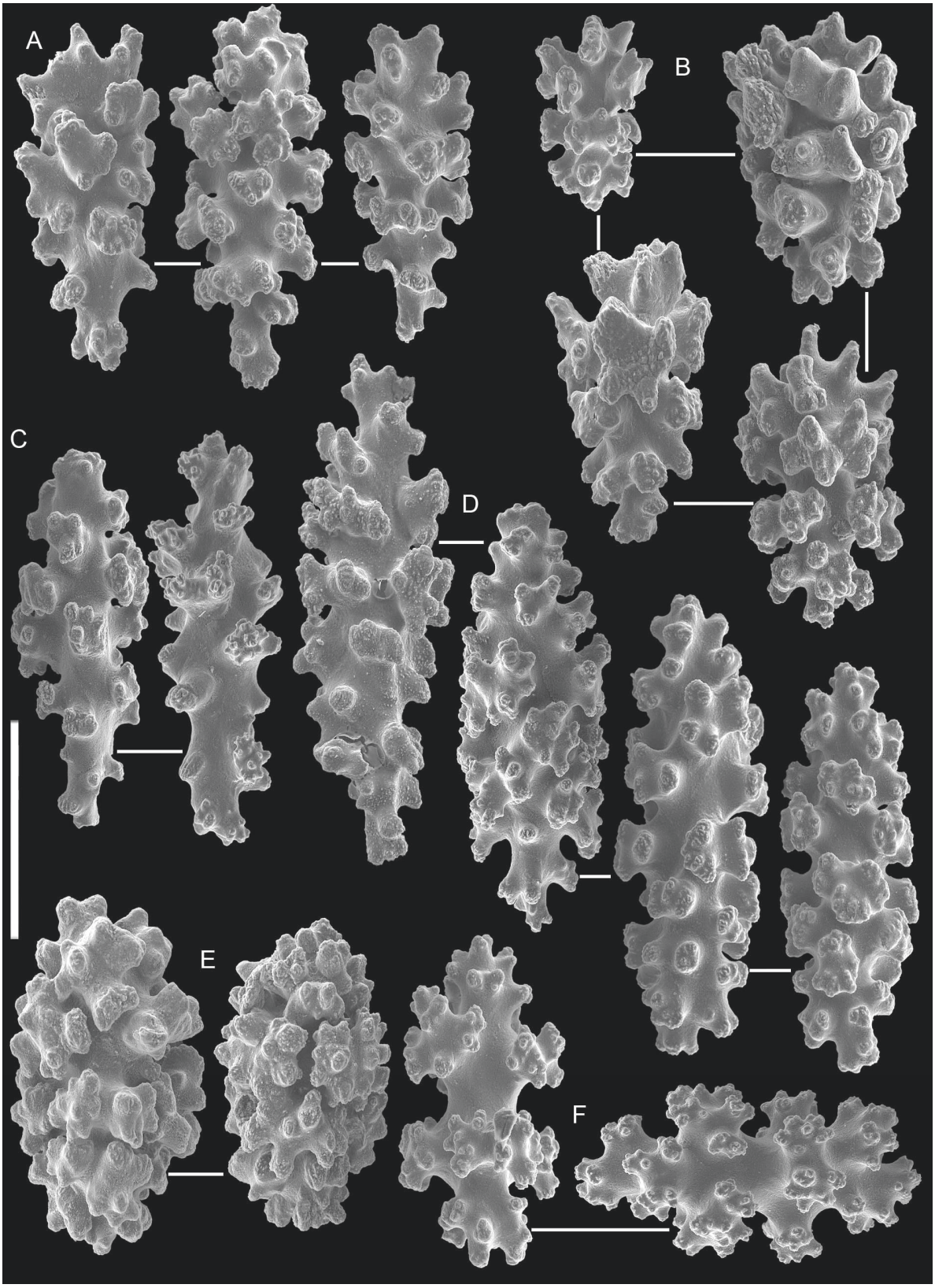

Fig. 3. *Calcigorgia herba* sp. nov., holotype MIMB 20744, sclerites from the polyp body wall. **A**. Warty clubs. **B**. Poorly developed clubs with leafy processes. **C**. Club-like spindles. **D**. Plump spindles with well-developed warts. **E**. Ovals. **F**. Capstans (8-radiate) with girdled warts. Scale bar = 0.1 mm.

and capstans, mostly 0.14–0.16 mm, ornamented with girdled warts (Fig. 3F). Clubs, spindles and ovals abundant. Capstans not numerous.

Outer coenenchyme layer with numerous 8-radiate capstans, mostly 0.15–0.16 mm long (Fig. 4A). Massive capstans, up to 0.18 mm long, with very developed warts, transitional to ovals, up to 0.18 mm long, bearing densely crowded processes (Fig. 4B). Internal layer of coenenchyme contains weakly calcified capstans, up to 0.15 mm long, of same shape as those in outer layer.

Paratype and variations

Paratype MIMB 20745 colony shape and size similar to holotype – 159 mm high and 9 mm wide (Fig. 1B). Polyp body wall smooth and cylindrical; tentacles folded over the polyp and partly retracted to the inside (Fig. 1G). Sclerites composition (Figs 5–7) coincides with that in holotype (Figs 2–4). The only difference is some greater calcification of sclerites in polyp body wall of paratype – its warty clubs (Fig. 6A) and poorly developed clubs (Fig. 6D) with more wide heads than those in holotype (Fig. 3A–B). Club-like spindles in paratype slightly longer – up to 0.25 mm in polyp tentacles (Fig. 6B) vs 0.23 mm in holotype (Fig. 2F). Short, poorly developed clubs and ovals longer in polyp body wall of

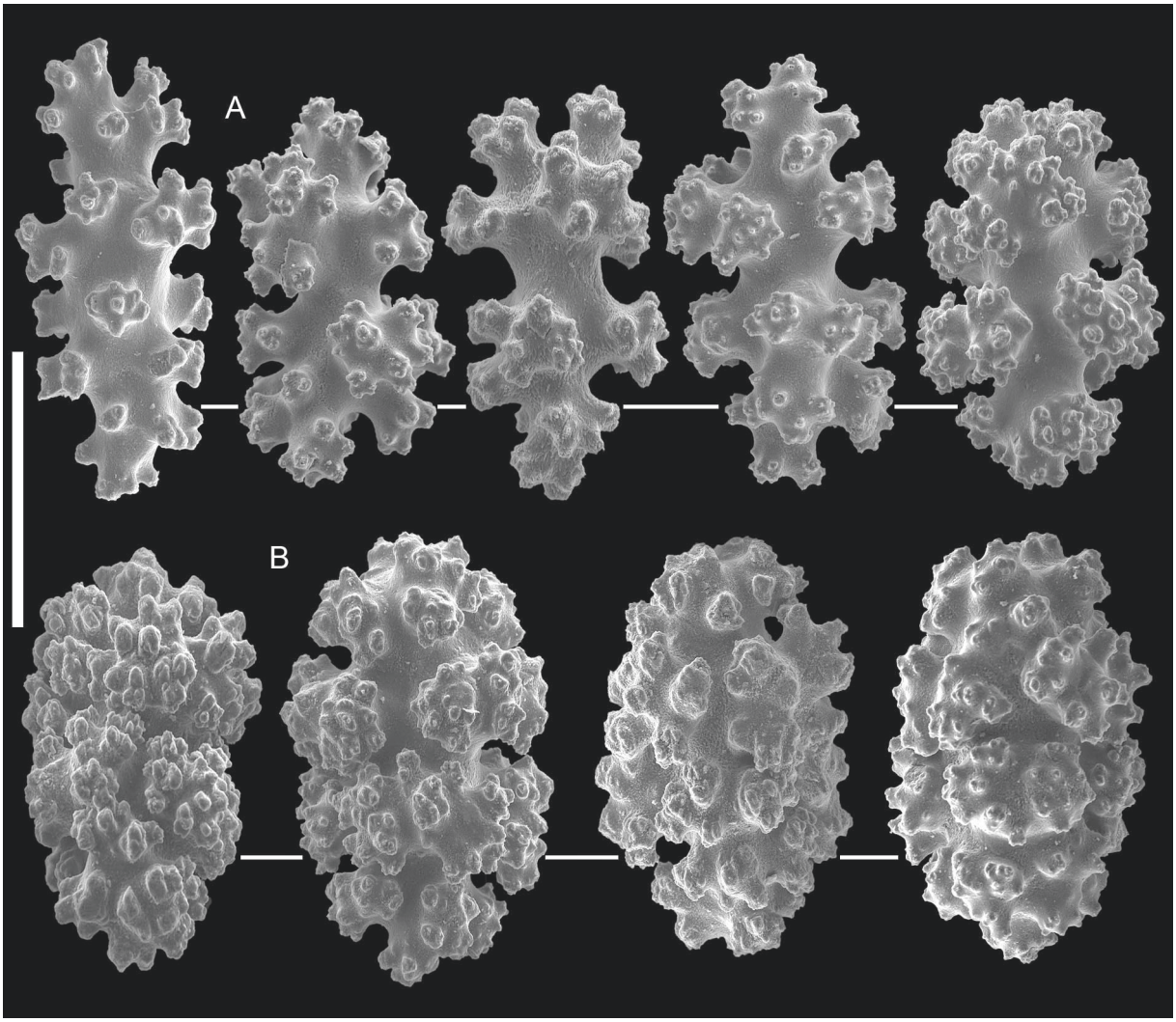

Fig. 4. *Calcigorgia herba* sp. nov., holotype MIMB 20744, sclerites from the coenenchyme. **A**. Well calcified capstans (8-radiate). **B**. Ovals. Scale bar = 0.1 mm.

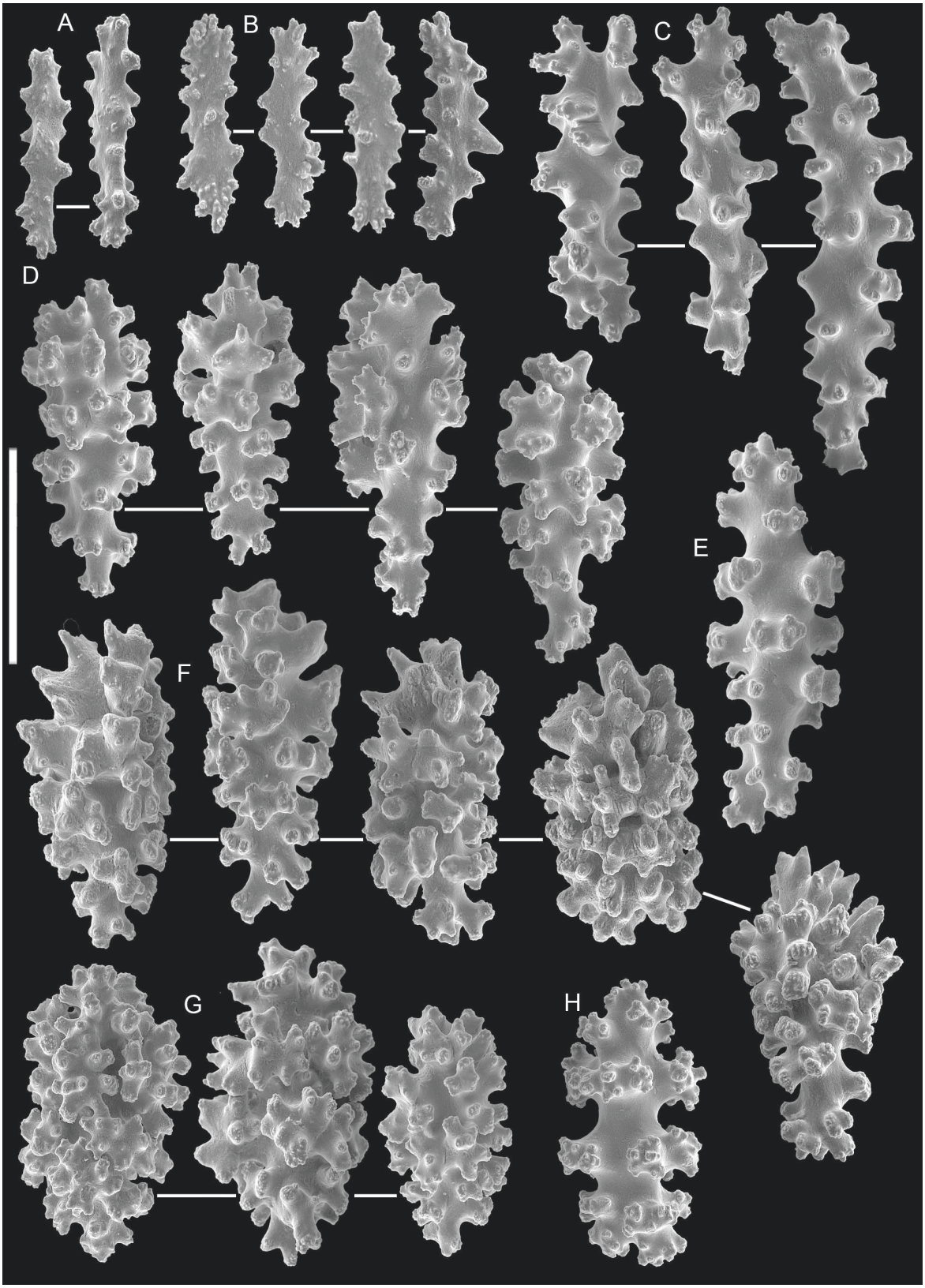

Fig. 5. *Calcigorgia herba* sp. nov., paratype MIMB 20745, sclerites from the tentacles of polyp. **A**. Modified clubs. **B**. Scales. **C**. Spindles. **D**. Warty clubs. **E**. Spindle. **F**. Poorly developed clubs with serrated processes. **G**. Ovals. **H**. Capstan (8-radiate). Scale bar = 0.1 mm.

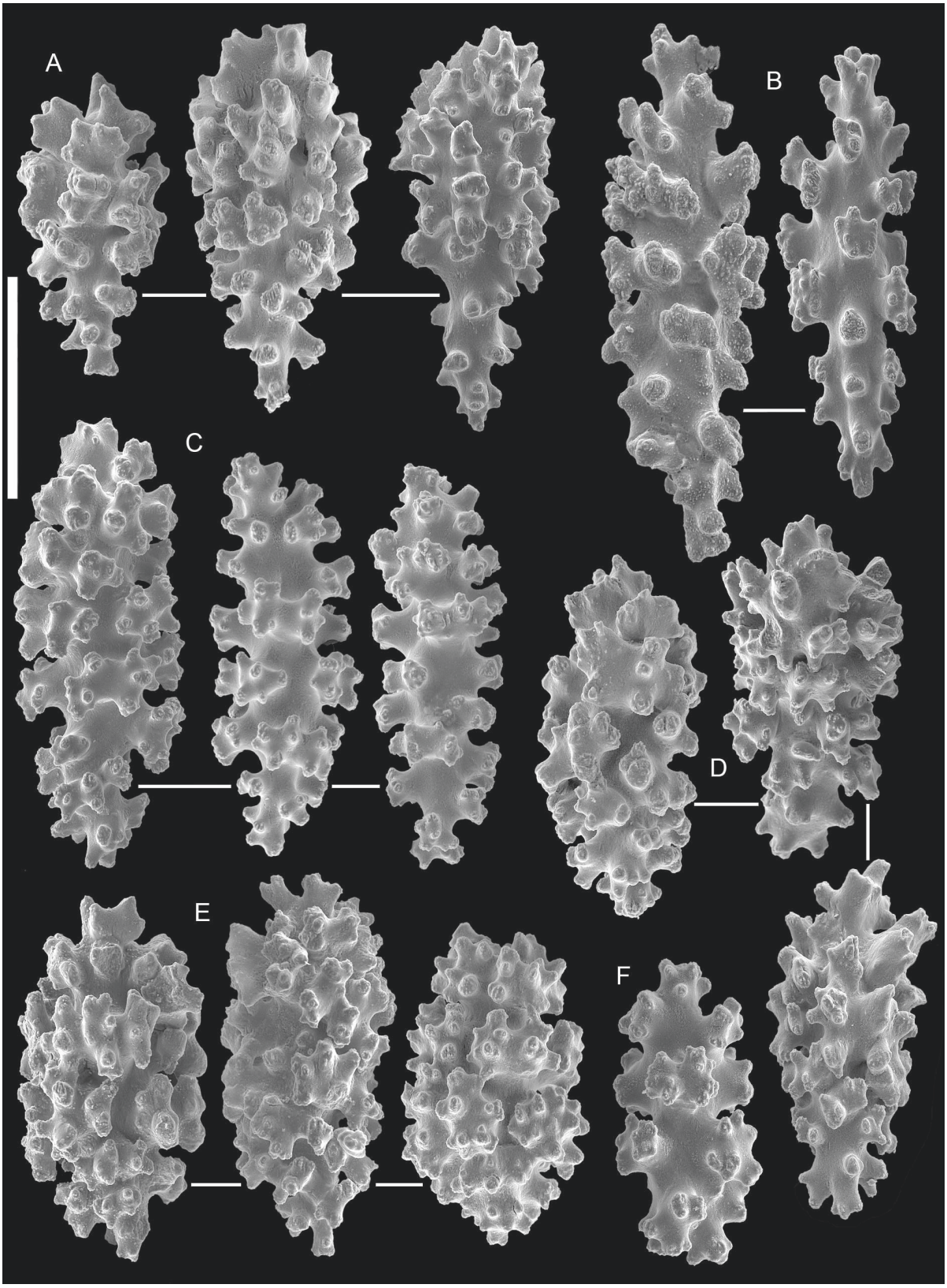

Fig. 6. *Calcigorgia herba* sp. nov., paratype MIMB 20745, sclerites from the polyp body wall. **A**. Warty clubs. **B**. Club-like spindles. **C**. Plump spindles with well-developed warts. **D**. Poorly developed clubs with serrated processes. **E**. Ovals. **F**. Capstan (8-radiate). Scale bar = 0.1 mm.

the paratype – up to 0.18 mm (Fig. 6D–E) vs 0.16 mm in holotype (Fig. 3B, E). Plump spindles of same size numerous in both paratype (Fig. 6C) and holotype (Fig. 3D). The coenenchyme of the paratype double-layered as in holotype, with 8-radiate capstans, up to 0.16 mm long (Fig. 7A), and well calcified ovals up to 0.18 mm long (Fig. 7B).

Colour

In alcohol-preserved material: polyps and coenenchyme creamy; colony axis black or deeply brown, sclerites colourless.

Remarks

The most obvious distinctive characters of *C. herba* sp. nov., differing from characters of other known members of the genus, are the shape of colony (with slender smooth stem and polyps crowded in the terminal part of the colony) and the presence of two different types of clubs among the sclerites. One

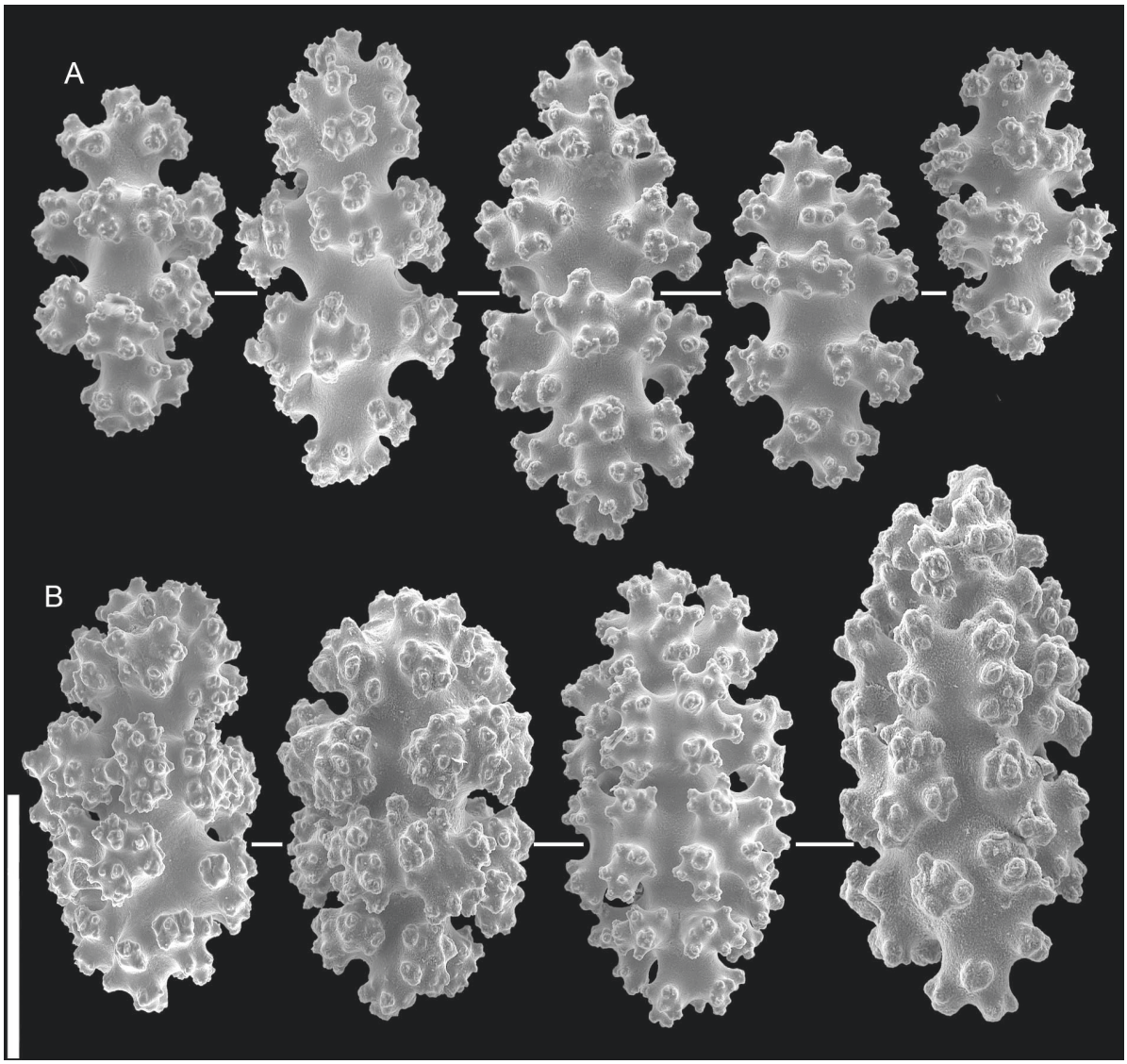

Fig. 7. *Calcigorgia herba* sp. nov., paratype MIMB 20745, sclerites from the coenenchyme. **A**. Well calcified capstans (8-radiate). **B**. Ovals. Scale bar = 0.1 mm.

Table 1 (continued on the next page)**.** Distinctive characters of species in the genus *Calcigorgia* Broch, 1935. The greatest length for the different types of sclerites and maximal sizes of polyps are provided in mm. * = from Matsumoto *et al*. (2019); (?) = unclear data from Matsumoto *et al*. (2019), see explanations in the text.

	C. beringi (Nutting, 1912)*	*C. gigantea* Matsumoto, Ofwegen & Bayer, 2019	*C. gracilis* Matsumoto, Ofwegen & Bayer, 2019	*C. herba* sp. nov.	*C. japonica* Dautova, 2007	*C.* sp. *	*C. lukini* sp. nov.	*C. matua* Dautova, 2018	*C. pacifica* Matsumoto, Ofwegen & Bayer, 2019	*C. simushiri* Dautova, 2018	*C. spiculifera* Broch, 1935
Colony shape after fixation	Branched with lateral ramification in different directions	Branched with lateral ramification in different directions	Sparsely branched in an openly pinnate manner, not strictly in one plane	Branched with lateral ramification in different directions	No data	Branched with lateral ramification in different directions	Branched with lateral ramification in different directions	Branched more or less in a plane	Branched with lateral ramification in different directions	Branched with lateral ramification in different directions	Branched in different directions
Polyp shape	Cylindrical	Cylindrical	Cylindrical	Cylindrical	With a thin folded middle part	Cylindrical	Cylindrical	Cylindrical, slightly widening downward	Cylindrical	Cylindrical	Cylindrical
Polyp height × width	1.75 × 1	10 × 6	1.75 × 0.8	3 × 2	5 × 2.2	5 × 2	1.8 × 2	5 × 2.5	2 × 1	10 × 4	5 × 3 (3 × 1.6*)
Tentacular sclerites:											
Warty rods	–	–	–	0.11	–	–	–	–	–	–	–
Flattened bodies or scales	0.1	–	0.12	0.11	–	–	–	0.9	0.05	–	0.12
Warty clubs	–	–	–	0.2	–	–	–	0.15	–	0.35	0.25
Serrated (dentate) clubs	–	–	–	–	0.29	–	–	–	–	–	–
Leafy clubs	–	–	–	0.15	–	–	0.2	0.18	–	–	–
Spindles	–	–	–	0.22	0.32	–	0.19	0.18	–	0.4	0.25
Club-like spindles	–	–	–	0.25	0.32	–	–	–	–	0.3	0.25
8-radiate capstans	–	–	–	0.14	–	–	0.18	–	–	–	–
Ovals	–	–	–	0.19	–	–	0.19	–	–	–	–

Table 1 (continued).

	C. beringi (Nutting, 1912)*	*C. gigantea* Matsumoto, Ofwegen & Bayer, 2019	*C. gracilis* Matsumoto, Ofwegen & Bayer, 2019	*C. herba* sp. nov.	*C. japonica* Dautova, 2007	*C.* sp. *	*C. lukini* sp. nov.	*C. matua* Dautova, 2018	*C. pacifica* Matsumoto, Ofwegen & Bayer, 2019	*C. simushiri* Dautova, 2018	*C. spiculifera* Broch, 1935
Polyp body wall sclerites:											
Warty or tuberculated clubs	–	–	0.17 (?)	0.18	0.16	–	–	0.15	0.2	0.28	0.22
Serrated (dentate) clubs	–	–	–	–	0.29	0.35	–	–	–	–	–
Leafy clubs	–	–	–	0.18	–	–	–	0.15	–	–	–
Spindles	0.15	0.9 (?)	0.3	0.21	0.35	0.35	–	0.17	0.2	0.4	0.25 (0.36*)
Club-like spindles	–	0.6 (?)	0.3	0.18	0.35	–	–	0.17	–	0.4	0.25
8-radiate capstans	0.1	–	–	0.16	–	–	0.18	0.17	–	–	–
Capstans with unordered processes	–	–	–	–	–	–	–	–	–	0.15	0.22
Ovals	0.1	–	–	0.18	–	–	0.19	0.17	–	0.15	0.22
Coenenchymal sclerites:											
Warty clubs	–	–	–	–	0.13	–	–	0.15	–	–	–
Leafy clubs	–	–	–	–	–	–	–	0.09	–	–	–
Clubs with simple tubercles	–	–	–	–	–	–	–	–	0.1 (?)	–	–
Spindles	0.15	0.5	0.12	–	0.26	–	–	0.13	0.1 (?)	0.19	0.25 (0.15*)
Club-like spindles	–	–	–	–	–	–	–	–	–	–	0.25 (0.11*)
8-radiate capstans	0.1	–	0.12 (?)	0.16	–	0.12	0.19	0.15	0.1 (?)	–	–
Capstans with unordered processes	–	–	–	–	–	–	–	–	–	0.15	0.2 (0.11*)
Ovals	0.1	–	0.12	0.18	–	–	–	0.15	–	0.15	0.2 (0.11*)

of these types, the poorly developed clubs with notched leafy processes on their heads and short warty handle, has not been described before in any of the known species of the genus (Figs 2E, 3B, 5F, 6D, Table 1). Moreover, only *C. herba* sp. nov. has warty rods along with scales in the tentacles (Fig. 2A, Table 1) and two types of sclerites in the coenenchyme – 8-radiate capstans and ovals (Figs 4A–B, 7A–B, Table 1).

C. herba sp. nov. coincides with *C. lukini* sp. nov. having ovals and capstans in the tentacles but the last has no clubs in the polyp body (Table 1). The composition of the sclerites in the polyp body wall of *C. herba* sp. nov. coincides with that of *C. spiculifera*, *C. matua* and *C. simushiri* as all these species have warty clubs, spindles, capstans and ovals in that part of polyp (Table 1). However, only *C. herba* sp. nov. has poorly developed leafy clubs with thick warty handles in that part of polyp (Figs 3B, 6D, Table 1). Furthermore, *C. simushiri* has long-handled clubs that are missing in *C. herba* sp. nov. (Table 1). Thus, the morphology of polyps and composition and size of sclerites in the polyp and coenenchyme distinguish *C. herba* sp. nov. from all previously described representatives of the genus.

Distribution

This species is known for certain from the Kurile Islands, Sea of Okhotsk, Northwestern Pacific, between 75 and 200 m depth.

Calcigorgia lukini sp. nov.

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Figs 8–12, Table 1

Diagnosis

Calcigorgia colonies scantly branched in several planes, with short smooth stem. Polyps remote from each other, arranged irregularly on surface of the branch, in alcohol-preserved material up to 1.8 mm high and up to 1.8 mm wide. Body walls of polyps with smooth surface; lower parts of polyps slightly widened. Polyp tentacles with warty spindles, poorly developed clubs with leafy processes on head, ovals and 8-radiate capstans. Polyp body walls with 8-radiate capstans and ovals. Both layers of coenenchyme with 8-radiate capstans; outer layer may contain ovals.

Etymology

The specific epithet is given in honor of Dr Vladimir Lukin, enthusiastic researcher of marine biodiversity in the National Scientific Centre of Marine Biology FEB RAS, who made a great collection of invertebrates in the Sea of Okhotsk in the 1980s.

Material examined

Holotype

SEA OF OKHOTSK – **Kurile Islands** • 95 × 59 mm; Iturup Is.; expedition of PFRC and ZIN RAS on RV *Tikhookeansky*; 44°38′ N, 146°55′ E; depth 100 m; 28 Sept. 1987; S. Grebelnyi leg.; dredged; MIMB 20710.

Paratype

SEA OF OKHOTSK – **Kurile Islands** • 112 × 44 mm; Iturup Is.; expedition of PFRC and ZIN RAS on RV *Tikhookeansky*; 44°31′ N, 147°06′ E; depth 50 m; 15 Sept. 1987; S. Grebelnyi leg.; dredged; MIMB 20712.

Fig. 8. *Calcigorgia lukini* sp. nov. **A**. Holotype MIMB 20710, Kurile Islands, Sea of Okhotsk. **B**. Paratype MIMB 20712, Kurile Islands, Sea of Okhotsk. **C**. Specimen from the Urup Is., Kurile Islands, Sea of Okhotsk, MIMB 20691. **D**. Side polyps, holotype MIMB 20710. **E**. Terminal polyps, MIMB 20691. **F**. Side polyps, MIMB 20743. Scale bars: A–C = 20 mm, D–F = 10 mm.

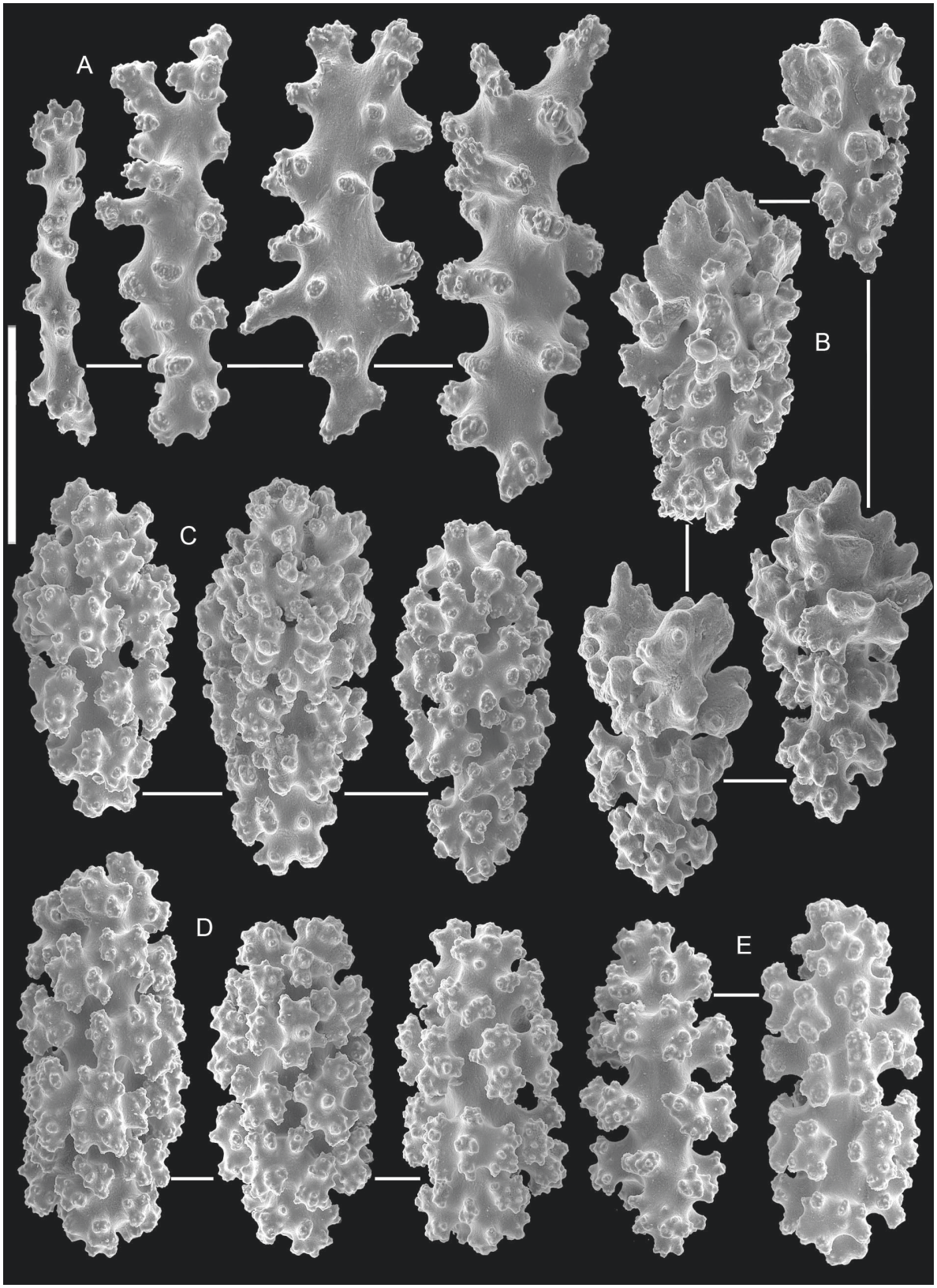

Fig. 9. *Calcigorgia lukini* sp. nov., holotype MIMB 20710, sclerites from the tentacles of polyp. **A**. Warty spindles. **B**. Clubs with leafy processes. **C**. Asymmetrical ovals. **D**. Symmetrical ovals. **E**. Capstans (8-radiate). Scale bar = 0.1 mm.

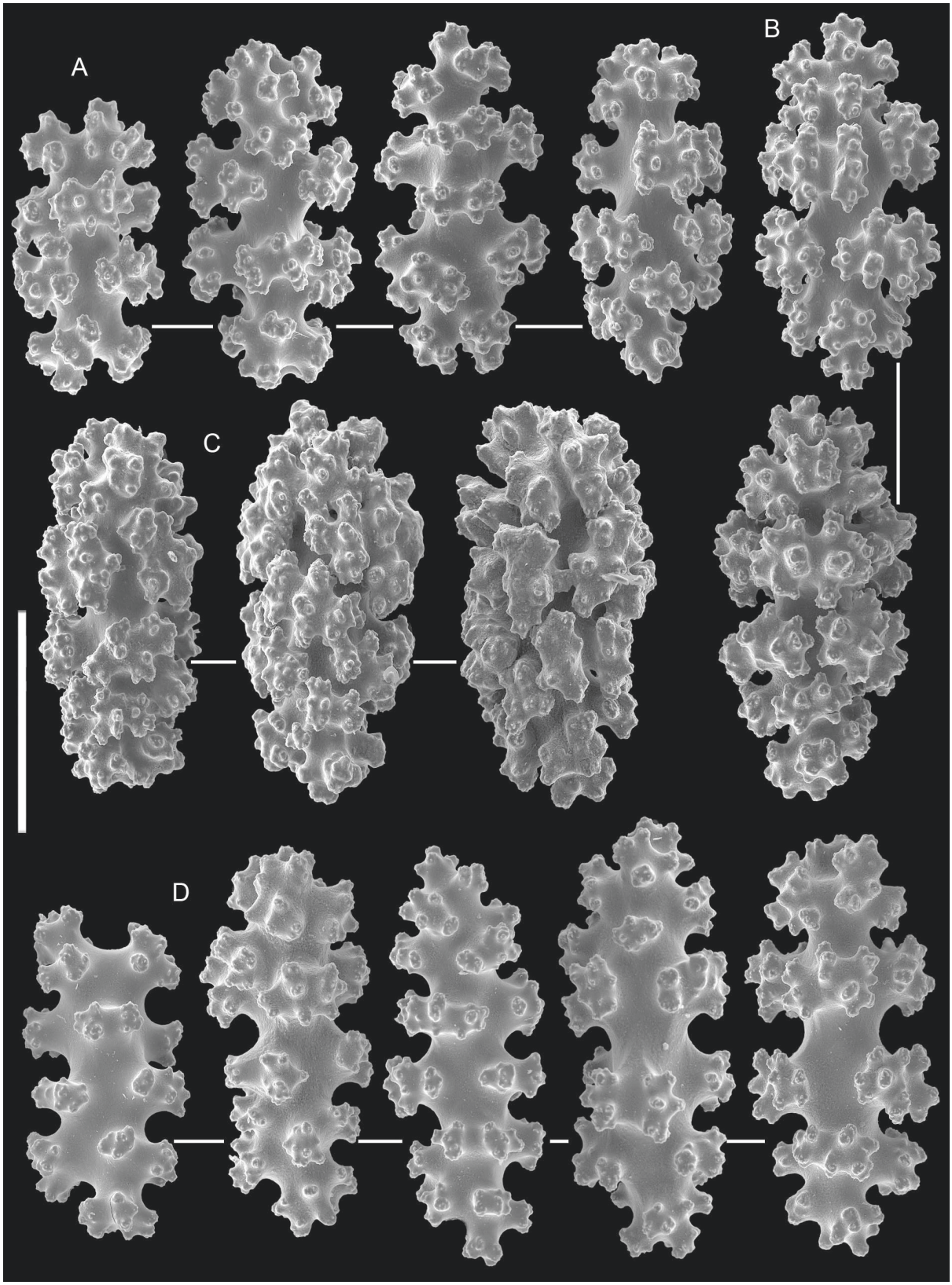

Fig. 10. *Calcigorgia lukini* sp. nov., holotype MIMB 20710, sclerites. **A**. Capstans from polyp body wall. **B**. Well calcified capstans from polyp body wall. **C**. Ovals from polyp body wall. **D**. Capstans (8-radiate) from the coenenchyme. Scale bar = 0.1 mm.

Additional material

SEA OF OKHOTSK • 1 specimen; Urup Is., Kurile Islands; 45°54′ N, 149°59′ E; depth 60 m; 12 Oct. 1973; Artemov leg.; dredged; MIMB 20691 • 1 specimen; Shelikhov Bay; cruise of RV *Akademik Oparin*; 60°02′ N, 158°24′ E; depth 60 m; 19 Aug. 2008; Nikolay Selin leg.; dredged; MIMB 20743.

Description

Holotype

Holotype alcohol-preserved colony 95 mm high and 59 mm wide, scantily branched (Fig. 8A). Side branches flexible, placed irregularly. Polyps up to 1.5 mm high and 2 mm wide, disposed irregularly at distances of 1–2 mm from each other. Tentacles folded over polyp and partly retracted to inside; polyp body smooth and cylindrical in shape (Fig. 8D).

Coenenchyme 0.8 mm thick, in two layers; a 0.6 mm thick outer layer, with smooth surface; a very thin inner layer, semi-transparent and longitudinally ridged. Axis with concentric layers without any visible mineralization. The axial canal present, but very narrow and hardly visible in the tip of the branches.

Tentacles with warty spindles, poorly developed clubs with a warty handle and leafy processes on head, ovals and capstans. Warty spindles, of irregular shape, branched, mainly 0.17–0.19 mm long, covered by granulated warts (Fig. 9A). Clubs mainly 0.12–0.19 mm long, sometimes up to 0.20 mm, with a plump head, consisting of several leafy processes (Fig. 9B). Short handle straight, thick and blunt, densely ornamented with small warts. Some longer clubs, up to 0.2 mm, with poorly developed leafy processes on head and very thick handle, are transitional to asymmetrical warty ovals (Fig. 9C). These ovals mainly up to 0.19 mm long, ornamented with small crowded warts tending to be conjunct (Fig. 9C). Symmetrical ovals well calcified, usually up to 0.18–0.19 mm long (Fig. 9D). Capstans mostly up to 0.18 mm long (Fig. 9E). These are well-calcified 8-radiate sclerites with two girdles of warts and plump terminal processes.

Numerous capstans (8-radiate) in body wall of polyps, mainly 0.16–0.18 mm long, with plump terminal warts (Fig. 10A). Well calcified capstans, up to 0.18 mm (Fig. 10B), transitional to warty ovals. Ovals, mostly 0.16–0.19 mm long, ornamented with warts tending to be conjunct (Fig. 10C).

Both layers of coenenchyme contain capstans, mostly 0.16–0.19 mm long (Fig. 10D). These well-calcified 8-radiate sclerites with two girdles of warts and plump terminal processes. Some capstans, up to 0.13 mm long, less calcified, but with well-formed and girdled warts.

Paratype and variations

Paratype MIMB 20712 colony shape and size similar to the holotype – 112 mm high and 44 mm wide (Fig. 8B). Polyps up to 1.6 mm high and 2 mm wide, disposed irregularly at distances of 1–2 mm from each other. Sclerites composition (Figs 11–12) coincides with that in the holotype (Figs 9–10). The only difference is smaller size of ovals and capstans in the polyp body wall and the coenenchyme of the paratype. Paratype's ovals shorter in polyp body wall – these mostly up to 0.16 mm long (Fig. 11C–D) vs up to 0.19 mm in the holotype (Figs 9C–D, 10C). Capstans in coenenchyme of the paratype mostly up to 0.15 mm long (Fig. 11F) vs up to 0.19 mm in the holotype (Fig. 10D).

Colour

In alcohol-preserved material: the polyps and coenenchyme creamy or light-brown; the colony axis black or deeply brown; sclerites colourless.

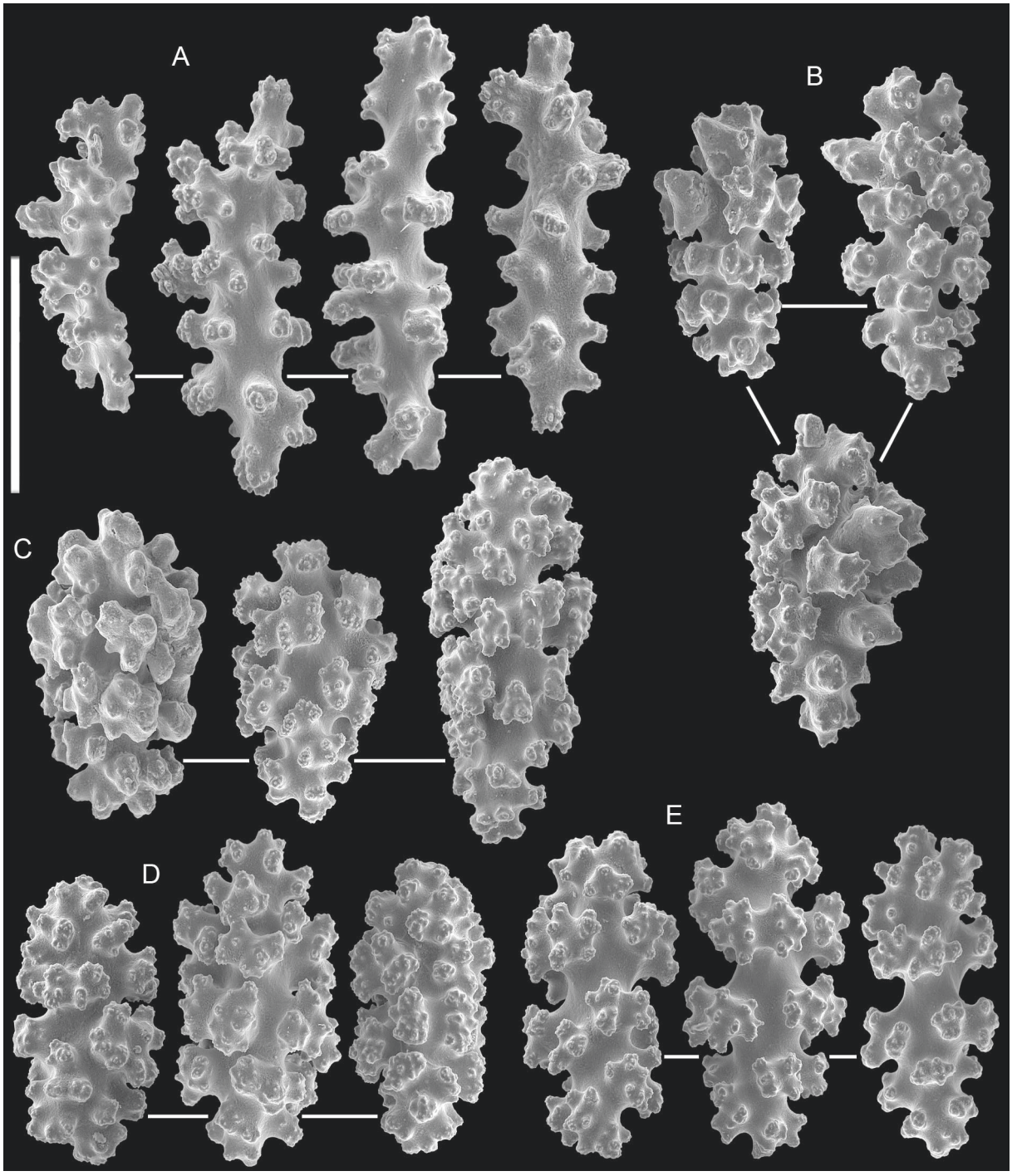

Fig. 11. *Calcigorgia lukini* sp. nov., paratype MIMB 20712, sclerites from the tentacles. **A**. Warty spindles from the tentacles. **B**. Clubs with leafy processes. **C**. Asymmetrical ovals. **D**. Symmetrical ovals. **E**. Capstans (8-radiate). Scale bar = 0.1 mm.

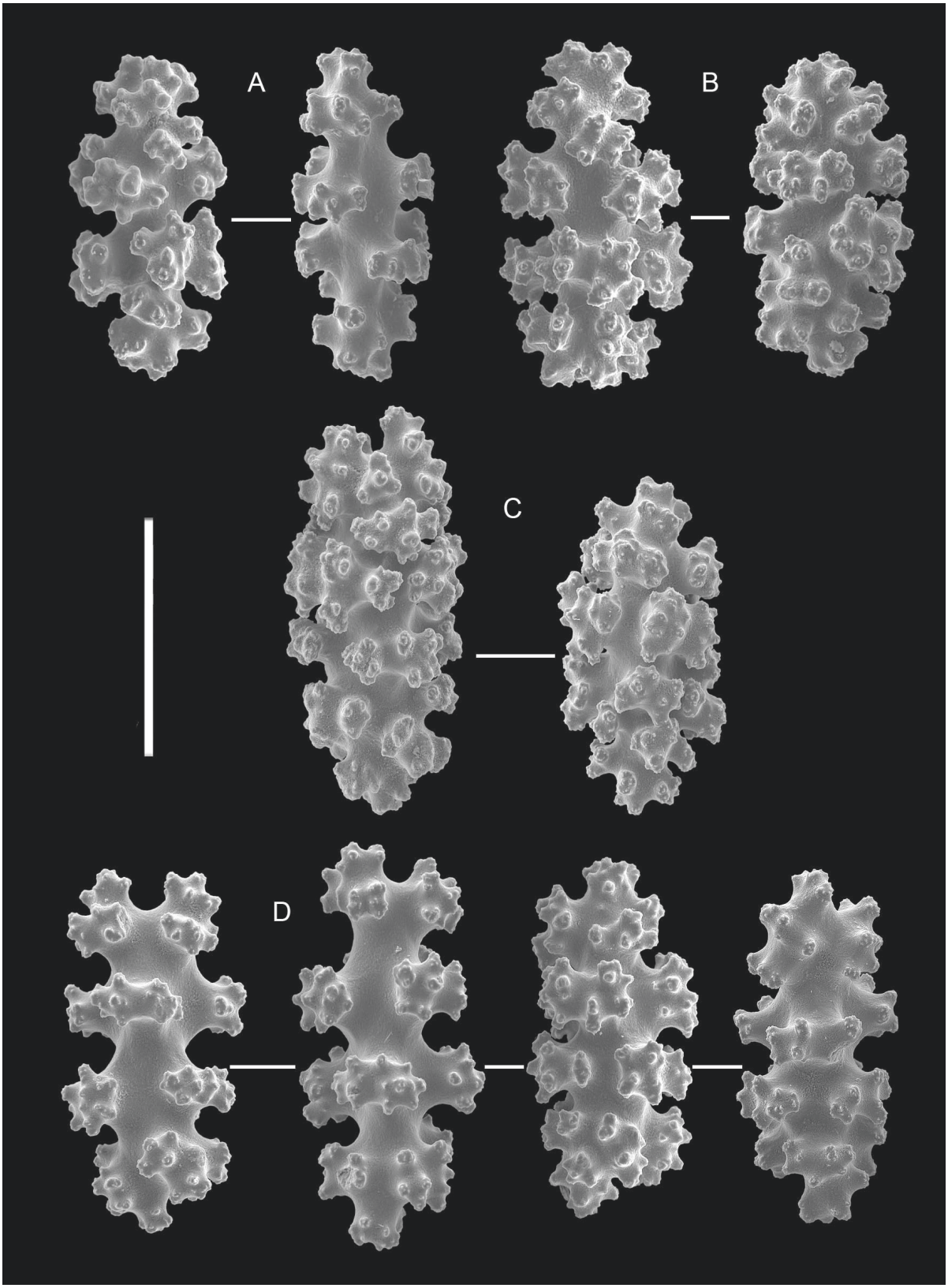

Fig. 12. *Calcigorgia lukini* sp. nov., paratype MIMB 20712, sclerites **A**. Capstans from polyp body wall. **B**. Well calcified capstans (8-radiate) from polyp body wall. **C**. Ovals from polyp body wall. **D**. Capstans (8-radiate) from the coenenchyme. Scale bar = 0.1 mm.

Remarks

Calcigorgia lukini sp. nov. presents a range of characters differing from other known species of the genus.

Polyps of *C. lukini* sp. nov. are somewhat smaller (with a low polyp body wall in fixed specimens, Fig. 8D–F), than those of other representatives of the genus. A scant set of the sclerite types (spindles, clubs, 8-radiate capstans and ovals) clearly differentiate this species (Table 1). Tentacles of *C. lukini* sp. nov. contain neither the warty clubs nor the flattened bodies that occur in other representatives of the genus (Table 1).

Calcigorgia lukini sp. nov. coincides with *C. herba* sp. nov. in the presence of poorly developed leafy clubs (Figs 2D, 3B, 5F, 6D, 9B, 11B) and spindles with tall and asymmetrically developed processes in polyp tentacles (Figs 2E, 5C, 9A, 11A). However, *C. lukini* sp. nov. differs from *C. herba* sp. nov. in the absence of warty rods, scales and warty clubs in tentacles and, also, in the absence of clubs in the polyp body wall (Table 1). Finally, *C. lukini* sp. nov. is the only species in the genus containing only capstans and ovals in the polyp body wall and a single sclerite type in the coenenchyme – 8-radiate capstans (Table 1). *C. gigantea* Matsumoto, Ofwegen & Bayer, 2019 also contains a single sclerite type in the coenenchyme, but these are spindles (Matsumoto *et al.* 2019).

Distribution

This species is known only from the Kurile Islands and Shelikhov Bay, Sea of Okhotsk, Northwestern Pacific, between 50 and 100 m depth.

Discussion

Corals are among the most widespread and important groups of marine macro-benthic animals, but the diversity and distribution of octocorals in deep-water areas of the Pacific have been studied unevenly (Roberts *et al.* 2006; Pérez *et al.* 2016). Within the temperate Northwest Pacific, the majority of the 30 recorded deep-water Octocorallia families have been reported only from a few areas where taxonomists have long been active – the Pacific part of Japanese waters (29 families) and the Northwest coast of America (23 families) (Wing & Barnard 2004; Heifetz *et al*. 2005; Herrera *et al*. 2010; Cairns & Hourigan 2017; Parrish *et al*. 2017; Stone & Cairns, 2017). Limited data exist for deep-sea octocorals from Far East seas, such as the western Bering Sea or the Sea of Okhotsk. The rich region of the Sea of Okhotsk (the area around the Kurile Islands, in particular) was beyond the scope of research on deep-water corals, and its Octocorallia fauna and taxonomy remained poorly studied (Dautova 2018a). It was 72 years after *Calcigorgia spiculifera* Broch, 1935, type species of the genus, was described from the Sea of Okhotsk that three additional species were recorded from the Sea of Japan and the area of the Kurile Islands (Dautova 2007, 2018b). Later, four new species were added to the genus from the area of the Aleutian Islands and Pacific coasts of the Japan (Matsumoto *et al.* 2019). One of these species was initially described as *Leptogorgia beringi* by Nutting (1912). Matsumoto *et al.* (2019) have redescribed it as *Calcigorgia beringi* (Nutting, 1912) based on an unpublished manuscript of the late Dr F.M. Bayer (USNM: National Museum of Natural History, Smithsonian Institution, Washington D.C., USA) in which the author proposed that re-description, and on the SEM images of USNM 30044, the holotype of *C. beringi* (see Matsumoto *et al.* 2019: 1).

In the present contribution, the taxonomic importance of the following characters is confirmed for the differentiation of the considered valid species in this genus: shape and size of polyps, colony branching pattern and distribution of polyps along the branches, and size and distribution of sclerites in the different parts of the colony. Clubs and spindles of different sizes and shapes and their distribution on the coral seem to be the most useful characters for distinguishing species of *Calcigorgia*, whereas

8-radiate capstans and ovals differ only in their length (Table. 1). On the other hand, new data on *Calcigorgia* sclerites presented here show that distribution of capstans and ovals in a colony also help to distinguish the new species. For example, *C. herba* sp. nov. and *C. lukini* sp. nov. are the only species that have capstans and ovals in the tentacles (Figs 2H, 5G, 9D, Table 1). However, the ovals from the coenenchyme of *Calcigorgia* species should be used with caution for taxonomy in the genus, because these could be derived from the capstans due to the very intense calcification process in the coral and may thus be absent otherwise.

Considering the above, the genus *Calcigorgia* Broch, 1935 includes at present time the following species: *C. beringi* (Nutting, 1912), *C. gigantea* Matsumoto, Ofwegen & Bayer, 2019, *C. gracilis* Matsumoto, Ofwegen & Bayer, 2019, *C. herba* sp. nov., *C. japonica* Dautova, 2007, *C. lukini* sp. nov., *C. matua* Dautova, 2018, *C. pacifica* Matsumoto, Ofwegen & Bayer, 2019, *C. simushiri* Dautova, 2018, *C. spiculifera* Broch, 1935 (type species), and *Calcigorgia* sp. from Matsumoto *et al.* (2019). The validity of *C. gigantea*, *C. gracilis* and *C. pacifica* is beyond doubt despite numerous mistakes and ambiguity in the descriptions of these species. For example, Matsumoto *et al.* (2019: 18) noted "Tentacles with a few scales, up to 0.05 mm long, with a few simple tubercles (Figure 15a)" in the *C. pacifica* description. However, a legend for the figure 15a says "*Calcigorgia pacifica* **sp. n.**, holotype RMNH Coel. 42108 **a** undeveloped spindles" (Matsumoto *et al.* 2019: 20). That figure, in fact, shows small scales; so these are designated in Table 1 of the present paper. Furthermore, the authors did not list the club-like spindles neither in the text nor in the legend for their figure 15 concerning sclerites of the *C. pacifica* holotype. Nonetheless, some sclerites on their figure 15b–c resemble club-like spindles, which are noted in Table 1 of the present paper. In the description of *C. gracilis*, these authors mentioned clubs in the polyp body but did not refer to any figures. These clubs are also mentioned in the caption for the SEM images of the sclerites of the *C. gracilis* holotype (Matsumoto *et al.* 2019: 10, fig. 7b). Unfortunately, images of sclerites in their figure 7 are neither connected nor circled by any auxiliary line (the same goes for the rest in that paper). This makes it difficult to understand which sclerites are marked with the letter "b". Some sclerites depicted to the right of the letter "b" in figure 7 of Matsumoto *et al.* (2019) resemble slender clubs, some others resemble spindles. As a result, information on distribution of sclerites in the different parts of the colony of *C. gracilis* and some other species in Matsumoto *et al.* (2019) is unclear (as marked in Table 1 of the present paper).

Designating the neotype of *C. spiculifera* Broch, 1935, Matsumoto *et al.* (2019) did not mention the presence of capstans and ovals in the polyps, the sclerite types that were pointed out and depicted by Broch (1935: 23, fig. 14b; Table 1 of the present contribution). The synonymization of *C. simushiri* with *C. spiculifera* performed by Matsumoto *et al.* (2019) raises serious doubts. The authors noted out: "The sclerites shown by Dautova (2018: Figure 7–13) for *C. simushiri* hardly differ from *C. spiculifera* (see discussion). Therefore we here synonymize *C. simushiri* with *C. spiculifera.*" This seems to be a misprinting, given that the authors completed this synonymization. *Calcigorgia simushiri* coincides with *C. spiculifera* only in terms of composition of sclerites while the sizes and shape of these sclerites clearly differ (Dautova 2018b: table 1). Thus, the clubs in *C. simushiri* are long-handled. The handles of the clubs and the spindles in *C. simushiri* bear conical hillocks inclined to ends of spindle (Dautova 2018b: 12, figs 7B–D, 8C, F, 9D, 11, 12C–D). Such kinds of clubs and spindles have never been documented in other *Calcigorgia* species. Furthermore, *C. simushiri* has two to three-times bigger polyps in comparison with those in *C. spiculifera* (Table 1 of the present contribution). However, Matsumoto *et al.* (2019: 26) considered *C. simushiri* Dautova, 2018 as intraspecific variation of *C. spiculifera* based, in fact, only on size of spindles of *C. spiculifera*. Therefore, the synonymization of these two species is concluded wrong.

The description of *C. japonica* extended by Matsumoto *et al.* (2019) is also doubtful. The authors did not compare sclerites of the *C. japonica* holotype listed and depicted in the paper of Dautova (2007:

302–304, fig. 3c–g) despite it being kept in the Zoological Institute RAS in St.-Petersburg, Russia, under the number ZIN 10706 (see Dautova 2007: 302); Matsumoto *et al.* (2019: 11–15, figs 9–12) instead depicted another specimen, ZIN 11678, from the same museum. The material described by them differs strongly from *C. japonica* Dautova, 2007 in: 1) no sclerites in the tentacles and warty clubs in the polyp, and 2) capstans present in the coenenchyme (Table 1 in present paper). Furthermore, the specimen ZIN 11678 has clubs with a distinct central wart on the heads that is unique in *Calcigorgia* (Matsumoto *et al.* 2019: fig. 11). Assuming the above, it should be validated as a new species of the genus (*Calcigorgia* sp.; Table 1 in present paper).

The new findings support the thesis that the genus *Calcigorgia* is more speciose than estimated in the past (Dautova 2018b). Additional work remains to be done on the genus, such as a molecular phylogenetic analysis. More material has to be obtained using modern trawling methods or remotedly operated vehicles, especially in the Sea of Okhotsk and around the Kurile Islands.

The geographic range of *Calcigorgia* remains to be updated and determined. The known range of each species has been restricted due to limited sampling. Only the type species, *C. spiculifera*, has been reported over a wide range from Alaska and the Aleutian Islands to the Sakhalin Island and the Kurile Islands (Broch 1935; Heifetz *et al.* 2005; Dautova 2007, 2008, 2011; Cairns & Hourigan 2017; Matsumoto *et*

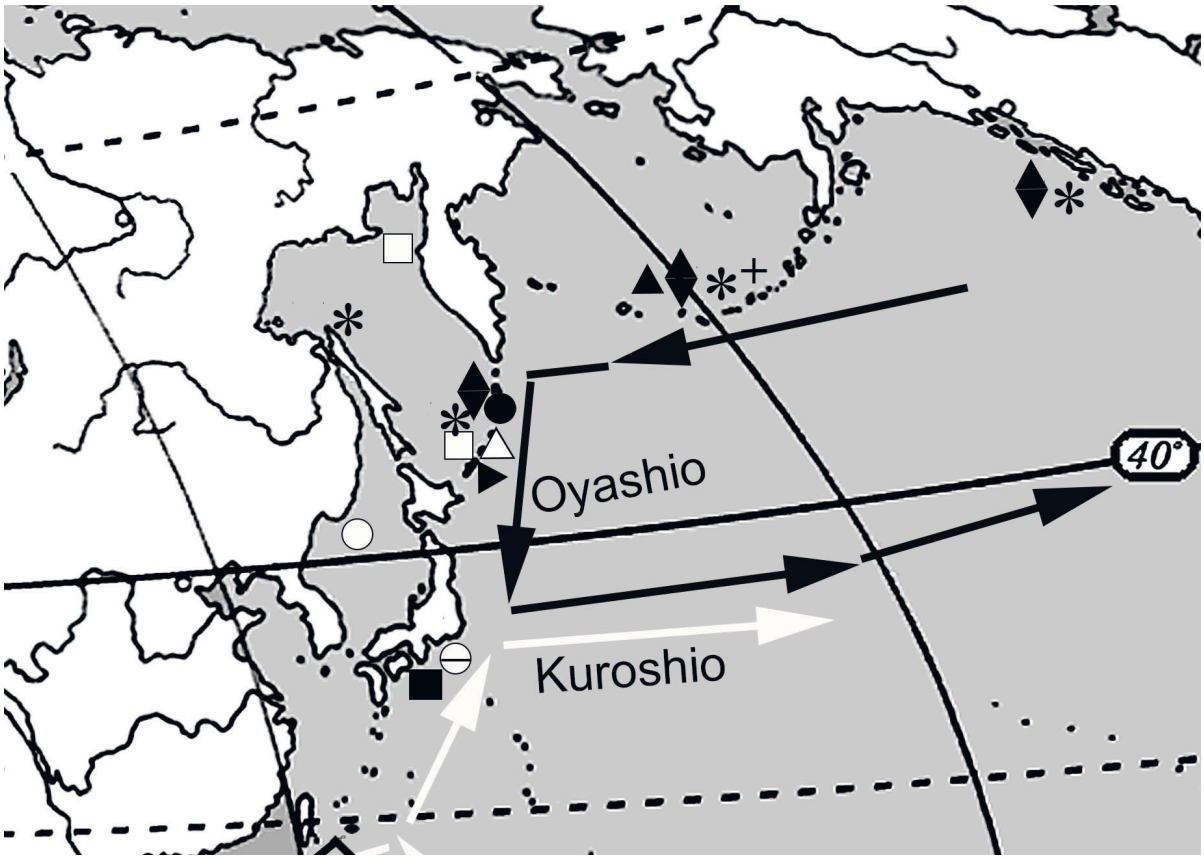

Fig. 13. Map of the distribution of the *Calcigorgia* gorgonians. The regions of *Calcigorgia* species collection (based on the literature and data in the present paper, see explanation in the text) are marked: ► = *C. beringi;* + = *C. gigantea;* Θ = *C. gracilis*; ● = *C. herba* sp. nov.; ○ = *C. japonica;* □ = *C. lukini* sp. nov.; Δ = *C. matua*; ■ = *C. pacifica*; ▲ = *C. simushiri*; * = *C. spiculifera*; ♦ = *Calcigorgia* sp. Black arrows indicate the direction of the Alaskan Stream and Oyashio Current; white arrows show the direction of the Kuroshio Current.

al. 2019; Fig. 13 of the present paper). The data presented here enlarge the known distribution of the genus by adding the area of the Shelikhov Bay (Sea of Okhotsk) and increase the number of species described in the genus. Among the representatives of *Calcigorgia*, *C. japonica* Dautova, 2007 has the southernmost distribution as it was recorded at 39°35′ N, 135°01′ E in the Sea of Japan (Dautova 2007). The other species of the genus have only been found north of this point (Dautova 2008, 2011, 2018b; Matsumoto *et al.* 2019). As a result, the genus *Calcigorgia* can be characterized as a cold-water (deep-water) group of gorgonians confined to the temperate Northern Pacific (Fig. 13).

A wide distribution is relatively common and accepted for tropical shallow Octocorallia genera and species (Roberts *et al.* 2006; Fabricius & Alderslade 2001). The widely distributed tropical and temperate shallow corals, such as *Sinularia*, *Lobophytum*, and nephtheids are well distributed by larval dispersal or vicariance events. Several species are able to disperse for long distances because their pelagic larvae can colonize new and distant regions (Hudges *et al*. 2000; Harii *et al.* 2002; Kahng *et al*. 2011).

For deep-water Octocorallia, primarily brooders with swimming planktonic larvae, little is known regarding duration of their larval life, but the role of currents in their dispersal inevitably remains highly significant (Cordes *et al.* 2001; Roberts *et al.* 2006; Watling *et al.* 2011; Beazley & Kenchington 2012; Pérez *et al.* 2016). The possible influence of currents, the East Kamchatka Current or the Oyashio, may be promising for understanding the dispersal of cold-water Octocorallia but has never been studied. The contemporary system of oceanic currents in the Northern Pacific suggests that there could be connections between the Octocorallia faunas of the Aleutian/Alaskan and Far East seas (Fig. 13). The Alaskan Stream moves south-westward along the Aleutian Islands as the western boundary current of the Alaska Gyre. It formes the Bering Sea Gyre in the deep part of the Bering Sea and becomes the East Kamchatka Current. This current moves south-westward along the east coast of the Kamchatka Peninsula and the Kurile Islands (naming the Oyashio Current south of the Bussol Strait, Ohtani 1970; Qiu 2001). However, the highest numbers of species are found in the Kurile Islands area (6 species, Fig. 13) but not in the Aleutian/Alaskan waters (4 species, Fig. 13).

The fact that the highest numbers of *Calcigorgia* species have been found in the Kurile Islands area, but not in the Aleutian Islands/Alaska area, contradicts the known system of the currents in the temperate Northern Pacific (Ohtani 1970; Qiu 2001; Fig. 13). It suggests that pathways for dispersal of the representatives of the genus in the Northern Pacific have to be reanalyzed. The definition of an evolutionary centre of origin for *Calcigorgia* species, for example in the Kurile Islands area, is a promising task to clarify the history of formation of the deep-water gorgonian fauna in the Pacific. It requires more knowledge regarding both the influence of the oceanic currents on the connectivity of coral communities and the genetic relationship between local faunistic complexes in the region.

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