ASED http://e-ASED.org
Animal Systematics, Evolution and Diversity

Anim. Syst. Evol. Divers. Vol. 33, No. 2: 65-72, April 2017
https://doi.org/10.5635/ASED.2017.33.2.063

Three Records of the Genus *Tubastraea* (Anthozoa: Hexacorallia: Scleractinia: Dendrophylliidae) from Korea

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ABSTRACT

This study reports three species in the genus *Tubastraea* from Korea: *Tubastraea coccinea* Lesson, 1829; *Tubastraea faulkneri* Wells, 1982; and *Tubastraea micranthus* (Ehrenberg, 1834). *Tubastraea faulkneri* and *T. micranthus* are newly recorded in Korea. The specimens of three species were collected in the subtidal zones off Jeju-do between 1991 and 2010. The two newly recorded species were described in detail based upon the morphological characters of skeletal structures. The previous records of *T. coccinea* in Korea were supplemented with additional data in the remarks. These three species have a straight septal arrangement or irregular septal fusion in common as a main character for the genus *Tubastraea*, but they differ with respect to the growth form, intercorallite distance, exsertness from common coenosteum, and the detailed characters of septal arrangement. *Tubastraea faulkneri* is similar to *T. coccinea* in its plocoid growth form, well developed common coenosteum, and corallite size. However, unlike the latter species, the former species is characterized by rare or absent budding adjacent to the corallite edges, wider intercorallite distance, and irregularly developed septal fusion near the columella. In particular, *T. micranthus* is distinguished by an axial dendroid growth form, and the smallest corallites in this genus.

Keywords: *Tubastraea coccinea*, *T. faulkneri*, *T. micranthus*, new records, Korea

INTRODUCTION

The genus *Tubastraea* in the family Dendrophylliidae consists of seven extant species worldwide according to the World Register of Marine Species (WoRMS) (Cairns, 2015). The current list of the species in this genus has been made through the discussions and subsequent synonymization processes by Boschma (1953), Eguchi (1968), and Wells (1982, 1983) (see Cairns, 1994, 2001).

Tubastraean species are distributed circumtropically in the Atlantic, Indian, and Pacific oceans (Cairns, 1994, 2001; Cairns et al., 1999). Three tubastraean species were reported in Korea before 2004: *Tubastraea coccinea* (Ehrenberg, 1834) (see Song, 1982); *T. aurea* (Quoy and Gaimard, 1833) (see Song, 1982); and *T.* (previously *Dendrophyllia*) *micranthus* (Ehrenberg, 1834) (see Song, 1991). Then, Song (2004) revised that only one tubastraean species, *T. coccinea* Lesson, 1829, had been previously recorded in Korea. In brief, *T. aurea* in Song (1982) was synonymized with *T. coccinea* Lesson, 1829. *Tubastraea coccinea* in Song (1982) and *T.* (previously *Dendrophyllia*) *micranthus* in Song (1991) were synonymized with *Dendrophyllia arbuscula* van der Horst, 1922 and *D. ijimai* Yabe and Eguchi, 1934, respectively.

The genus *Tubastraea* is characterized by the absence of zooxanthellates, colonial and attached form, theca with granulated costae and porous intercostal striae, extratentacular budding, spongy columella, and straight or irregularly fused septal arrangement (Cairns, 2001). In particular, one of the main characters for the genus *Tubastraea* which differs from other genera in the family Dendrophylliidae is its normal septal arrangement or non Pourtalès plan (Cairns, 2001)[1] or irregular Pourtalès plan (Ogawa and Takahashi,

[1]Cairns (2001) noted, "The Pourtalès plan was first described by Pourtalès in 1871.… It is a form of septal substitution whereby the septa of the second and higher cycle bifurcate at their outer edges (edge adjacent to the synapticulotheca) but maintain their axial edges as one septum. The next cycle of septa forms within the space created by the bifurcated outer edge of the septa of the previous cycle and traditionally takes the number of that cycle, the bifurcated septal pair being renumbered to a higher cycle. This process may repeat for several cycles, resulting in the higher/highest cycle septa (those most recently formed) being the shortest septa and the other cycles being often curved, their axial edges joined in pairs." Cairns (2001) interprets the Pourtalès plan strictly as a regularly fused septal arrangement in contrast to the normal arrangement as a straight or irregularly fused septal arrangement.

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eISSN 2234-8190

1993)[1]. In this genus, growth form, corallite size, corallite exsertness from coenosteum, intercorallite distance, budding system, and septal arrangement could be useful characters to identify the species.

The present paper reports three tubastraean species from Korea: *Tubastraea coccinea* Lesson, 1829; *T. faulkneri* Wells, 1982; and *T. micranthus* (Ehrenberg, 1834). Two latter species are newly recorded in Korea. Meanwhile, Ogawa and Takahashi (1993) in Japan regarded *T. faulkneri* as a variation of *T. coccinea*. However, the present paper indicates that *T. faulkneri* differs as a species from *T. coccinea* in its budding from common coenosteum, wider intercorallite space, and detailed septal arrangement despite the similarities.

MATERIALS AND METHODS

The specimens were collected from the subtidal zones off Jeju-do, Korea from 1991 to 2010. They were dissolved in sodium hypochlorite solution with distilled water for 24 hours to remove all tissues, washed in distilled water, and dried to examine the skeletal structures. The growth forms and shapes of the coralla were photographed with digital cameras (G12; Canon Inc., Tokyo, Japan and Optio WG2; Pentax Ricoh Imaging Co. Ltd., Tokyo, Japan). The skeletal structures of the corallites were observed with a stereomicroscope (Leica S8APO; Leica Microsystems, Wetzlar, Germany), photographed with a mounted camera (Leica Microsystems), and measured with an image analyzer (LAS ver. 3.6; Leica Microsystems). The characters such as corallite size, fossa depth, intercorallite distance, and whole colony size were measured manually using a metric ruler.

The classification and the morphological terms used in this study are referenced from Wells (1956), Ogawa and Takahashi (1993), Cairns (1994, 2001), Cairns et al. (1999), Song (2004), and Cairns and Kitahara (2012). The specimens examined are deposited at the Ewha Womans University Natural History Museum, Korea.

The following abbreviations are used: GCD, greater calicular diameter; LCD, lesser calicular diameter; GCD : LCD, ratio of greater calicular diameter to lesser calicular diameter; ind., individual (singular); inds., individuals (plural); S, septal cycle.

SYSTEMATIC ACCOUNTS

Phylum Cnidaria Hatschek, 1888

Class Anthozoa Ehrenberg, 1834
Subclass Hexacorallia Haeckel, 1866
Order Scleractinia Bourne, 1900
Family Dendrophylliidae Gray, 1847

Diagnosis. Solitary or colonial. Growth forms reptoid or phaceloid or plocoid or dendroid or flabellate. Synapticulotheca developed. Pourtalès plan usually developed.

Genus *Tubastraea* Lesson, 1829

Diagnosis. Colonies plocoid or phaceloid or dendroid mainly formed by extratentacular budding. Costae granulated, intercostal striae porous. Epitheca absent. Septa straight or irregularly fused. Pali absent. Columella spongy.

***Tubastraea coccinea* Lesson, 1829**

Tubastraea coccinea Lesson, 1829: 93; Wells, 1983: 243, Pl. 18, figs. 1, 2; Veron, 1986: 580; Cairns, 1991: 26, Pl. 12c–e; 1994: 93, Pl. 39g–i; Ogawa and Takahashi, 1993: 98, Pl. 1, figs. 1–8, Pl. 2, figs. 1–4; Cairns and Zibrowius, 1997: 197; Song, 2004: 554, Pl. 78B–E, 79A; Tachikawa, 2005: 20, Pl. 13, figs. A–C; Lam et al., 2008: 736, fig. 2A, B; Dai and Horng, 2009: 161.

Lobophyllia aurea Quoy and Gaimard, 1833: 195, Pl. 15, figs. 7–11.

Tubastraea aurea: Eguchi, 1968: C68, Pl. C16, figs. 5, 6, Pl. 17, fig. 17, Pl. C26, figs. 2, 3; Song, 1982: 139, Pl. 3, figs. 11, 12; 1991: 137.

Previous record. Korea: Jeju-do: Seogwipo-si, Munseom (Song, 2004).

Material examined. Korea: 1 ind., Jeju-do: Seogwipo-si, Hyeongjeseom, 21 Oct 1998, Song JI, brown (EWZS 4115); 1 ind., Seogwipo-si, Munseom, 28 Dec 2003, Song JI, 4 m deep (EWZS 4122); 4 inds., Seogwipo-si, Nambangpaje, 24 Jun 2005, Song JI (KCRB 230, 231, 232, 233); 2 inds., Seogwipo-si, Beomseom, 20 Nov 2008, Song JI, 20–25 m deep (EWZS 4179); 1 ind., Seogwipo-si, Munseom, 29 Aug 2010, Hwang SJ, Kim MS, Reft A, Choi EA, 7 m deep, greenish brown, by SCUBA diving (EWZS 4180).

Remarks. *Tubastraea coccinea* was previously recorded in Korea, with the report stating that it has an orange-red coenosarc with yellow tentacles and oral margins. However, brown or greenish-brown specimens are newly reported from Korea in this study. In addition, the distribution of this species was extended westward in southern Jeju-do from Munseom in previous records to Hyeongjeseom in this report.

[1]Ogawa and Takahashi (1993) interpret the Pourtalès plan widely as all the septal fusions and then separate it in two types, namely the regular Pourtalès plan and the irregular Pourtalès plan.

Distribution. Circumtropical: Pacific Ocean: Korea (Jeju-do); Japan (Sagami Bay, Kii, Bungo Straits, Osumi Islands, Ryukyu Islands, Amakusa Islands); Taiwan; Hong Kong; Philippines (Mindoro and Zamboanga Peninsula); Indonesia (Banda Sea); Australia; USA (Gulf of California).

[1]***Tubastraea faulkneri* Wells, 1982 (Tables 1, 2, Fig. 1)**

Dendrophyllia aurea: van der Horst, 1926: 46, Pl. 2, fig. 1.
Tubastraea aurea: Boschma, 1953: 112, Pl. 9, figs. 5, 6.
Tubastraea faulkneri Wells, 1982: 216, Pl. 3, figs. 1–3; 1983: 244, Pl. 19, figs. 1–4; Veron, 1986: 580; Cairns, 1991: 27, Pl. 12j; Lam et al., 2008: 736, figs. 2C, D; Dai and Horng, 2009: 162.

Material examined. Korea: 1 ind., Jeju-do: Seogwipo-si, Mara-do, 25 Oct 1991, Song JI, Won JH, brown by SCUBA diving (EWZS 4118); 1 ind., Seogwipo-si, Munseom, 24 Jun 2005, Song JI (EWZS 3990).

Description. Corallum colonial, attached. Growth forms of well developed colonies massive, hemispherical, strongly

Table 1. Morphological characters of *Tubastraea faulkneri*

Characters			Mean (mm)	SD (mm)	n
Intercorallite distance (wall to wall)			5.11	2.89	45
Corallites	Calicular diameter	LCD	10.30	1.56	20
		GCD	11.60	1.57	20
	GCD : LCD		1.13	0.07	20
	Exsertness from coenosteum		5.85–13.10	2.60–7.17	20
Columella	Diameter	LCD	3.28	0.70	20
		GCD	5.44	0.92	20
Fossa	Depth		6.65	1.53	20
Septa	Total number		62.15	8.64	20
	No. of septa fused with columella		19.60	5.51	20
Costae	Width		0.32	0.07	113
Intercostal striae	Width		0.10	0.04	107

SD, standard deviation; n, sample size; LCD, lesser calicular diameter; GCD, greater calicular diameter; GCD : LCD, ratio of greater calicular diameter to lesser calicular diameter.

Table 2. Comparisons of morphological characters between *Tubastraea faulkneri* and *T. coccinea*

Characters		*T. faulkneri*		*T. coccinea*
		This study	Wells (1982), Cairns (1991)	Wells (1983), Cairns (1991), Cairns and Zibrowius (1997)
Corallites	LCD×GCD (mm)	7–13 (10.30)×8–14 (11.60)	8–13[a]	10–13[a]
	Exsertness from coenosteum (mm)	2–33 (5.85–13.10)	3–8[b]	Up to 12, rarely over 10[a]
Columella	LCD×GCD (mm)	2.17–5.18 (3.28)×4.02–7.08 (5.44)	Large[a]	Large[a]
Fossa	Depth (mm)	4–10 (6.65)	5–8[b]	Moderately deep[a]
Septa	Total number	45–78 (62.15)	≥48[a]	Up to 48[a]
	No. of septa fused with columella	12–27 (19.60)	12–24[a]	12[a]
	Cycle	Hexamerous, 4–5 cycles	Hexamerous, ≥4 cycles[a]	Hexamerous, 4 cycles[a]
	Size	S1≥S2>S3>S4 or S1≥S2>S3>outer S5>S4>inner S5	S1>S2>S4>S3[a]	S1, S2≫S4>S3[a]
	Fusion	S4 fused with S3 or S5 fused with S4	Prominent fusion of S4 to S3[b]	S4 united with S3[a]
Intercorallite distance (wall to wall) (mm)		1–12 (5.11)	Widely spaced, 5–15[b]	Closely spaced[a]
Color in living		Coenosarc brown, tentacles green (EWZS 4118)	Orange[b]	Yellowish green, yellow, pink, scarlet, reddish brown, orange[c], purple[d]

The number in parentheses for the data of the characters indicates the average.
LCD, lesser calicular diameter; GCD, greater calicular diameter.
[a]Cairns (1991), [b]Wells (1982), [c]Wells (1983), [d]Cairns and Zibrowius (1997).

Korean name: [1]*먼협나팔돌산호(신칭)

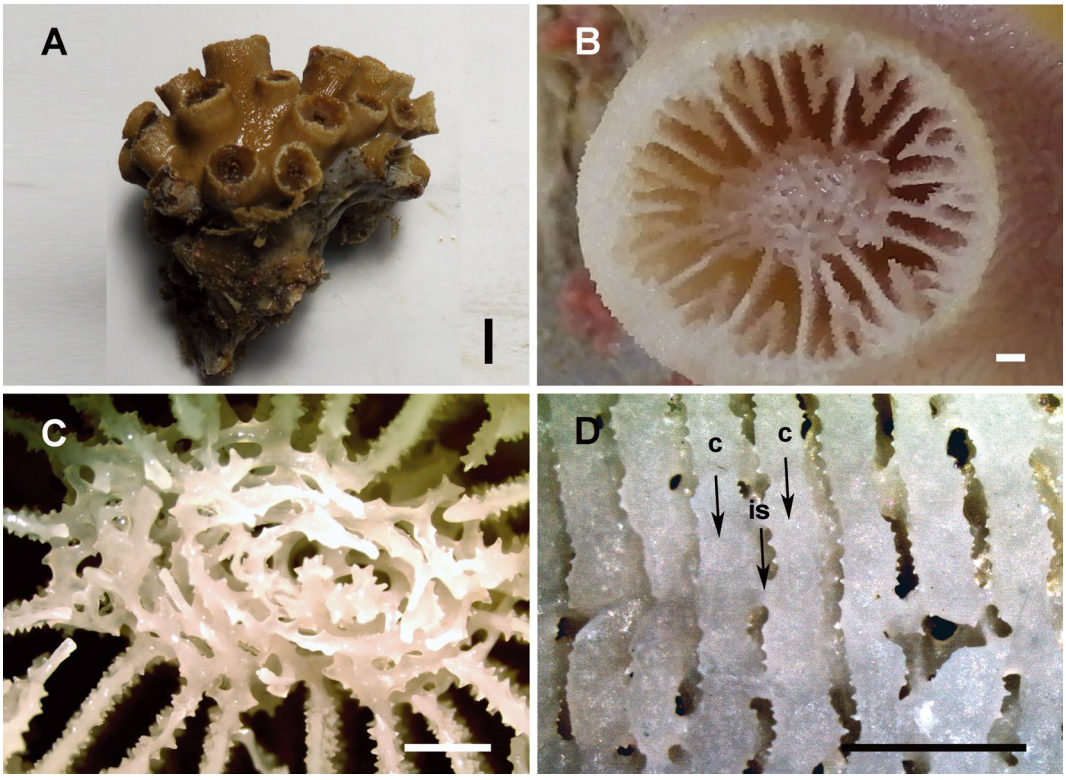

Fig. 1. *Tubastraea faulkneri* (EWZS 3990). A, Growth form, plocoid; B, Septal arrangement, irregularly fused; C, Columella, spongy; D, Costae (c) granulated, intercostal striae (is) porous. Scale bars: A = 1 cm, B–D = 1 mm.

convex, 30–90 mm in width, 35–85 mm in height. Corallites in plocoid arrangement. Corallites rarely directly adjacent. Intercorallite distance 1–12 mm. Extratentacular budding from common coenosteum, rarely from calice edges or walls of larger corallites in the middle of the colony. Branching absent or rare. Fully grown corallites cylindrical, 7–13 × 8–14 mm in calicular diameter (GCD : LCD 1.00–1.30), 2–33 mm in height or exsertness from common coenosteum. Calice elliptical or circular. Columella spongy, elliptical or circular or rudimentary, 2.17–5.18 × 4.02–7.08 mm in diameter. Fossa 4–10 mm in depth. Theca synapticulotheca, defined with costae, intercostal striae. Costae granulated, 0.16–0.54 mm in width. Intercostal striae porous, 0.04–0.25 mm in width. Septa irregularly straight, hexamerously arranged in 4–5 cycles. 12–27 septa fused with columella. Septal size and shape of corallites vary, even in one colony. In 4 cycles, S1 ≥ S2 > S3 > S4. In 5 cycles, S1 ≥ S2 > S3 > outer S5 > S4. Pairs of S5s fused before common outer S4 with outer S5 extending to columella or pairs of S4s fused before common S3 with outer S4 extending to columella. S1, S2 entire, inner edges vertical. Septal faces covered with small spines.

Color. Coenosarc brown, tentacles green (EWZS 4118).

Remarks. *Tubastraea faulkneri* is similar to *T. coccinea* in its plocoid growth form, corallite size, and corallite exsertness from the coenosteum. However, the former differs from the latter in its widely spaced (5–15 mm) corallites, which are sunken in thickened coenosteum, and prominent septal fusion between S3 and S4 (Wells, 1982). In addition, *T. coccinea* is distinguished by a large difference in septal size between S1, S2 and S3, S4 (Cairns, 1991, 1994; Cairns and Zibrowius, 1997). The specimens in this study are similar to *T. faulkneri* based on its rare or absent budding adjacent to the calice edges of larger corallites in the middle of the colony, wider intercorallite distance (more than 5 mm at average), and irregular or asymmetric fusion near columella in higher cycles of septa (Tables 1, 2).

A specimen (EWZS 4118) collected from Mara-do at the Southwest of Jeju-do is distinguished from those in the previous studies (Wells, 1982; Cairns, 1991) by following characters: higher range of corallite exsertness from common coenosteum (mean ± SD: 6.70–17.20 ± 1.64–7.61); strong septal arrangement seemingly like a typical Pourtalès plan; more numerous septa hexamerously arranged in 5 cycles (mean ± SD: 67.50 ± 8.10); and brown coenosarc with green tentacles.

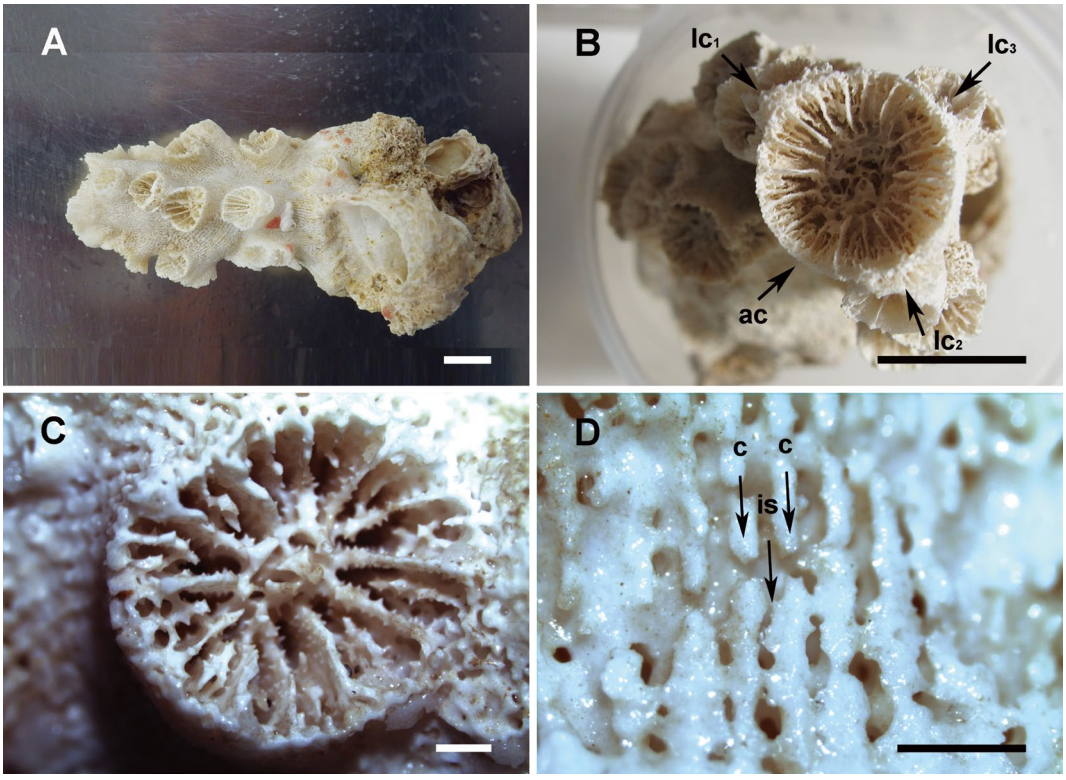

Fig. 2. *Tubastraea micranthus* (EWZS 6422). A, Growth form, dendroid; B, Axial corallite (ac) with 3 rows of lateral corallites (lc_1, lc_2, lc_3); C, Septal arrangement of lateral corallite, relatively straight; D, Costae (c) granulated, intercostal striae (is) porous. Scale bars: A, B = 1 cm, C, D = 1 mm.

Table 3. Morphological characters of *Tubastraea micranthus*

	Characters		Mean (mm)	SD (mm)	n
Axial corallites	Calicular diameter	LCD	9.33	3.21	3
		GCD	10.33	2.31	3
	GCD : LCD		1.11	0.14	3
	Height		27.67	28.22	3
	Septa	Total number	49.67	9.29	3
1st lateral corallites	Calicular diameter	LCD	6.29	0.92	12
		GCD	7.47	1.16	12
	GCD : LCD		1.19	0.08	12
	Height		7.00	2.76	12
	Columella	LCD	2.15	0.75	12
		GCD	2.64	0.79	12
	Fossa	Depth	4.25	1.06	12
	Septa	Total number	29.64	7.06	11
Costae		Width	0.23	0.05	66
Intercostal striae		Width	0.12	0.03	64

SD, standard deviation; n, sample size; LCD, lesser calicular diameter; GCD, greater calicular diameter; GCD : LCD, ratio of greater calicular diameter to lesser calicular diameter.

Distribution. Pacific Ocean: Korea (Jeju-do); Taiwan; Hong Kong; Philippines; Palau (Bailechesengel Island); Indonesia (Banda; Amboina); Ecuador (Isabela).

[1]***Tubastraea micranthus* (Ehrenberg, 1834)**
(Tables 3, 4, Fig. 2)

Oculina micranthus Ehrenberg, 1834: 304.

Korean name: [1]*잔가지나팔돌산호 (신칭)

Table 4. Comparisons of morphological characters between *Tubastraea micranthus* and *Dendrophyllia ijimai*

Characters		This study	*T. micranthus*	*D. ijimai*
			Nemenzo (1960), Ogawa and Takahashi (1993), Cairns and Zibrowius (1997), Tachikawa (2005)	Eguchi (1968), Cairns (1994), Ogawa and Takahashi (1995)
Colony	Growth form/branching	Axial corallite dendroid/branching absent	Axial corallite dendroid/branching uniplanar[a]	Axial corallite dendroid/ branching non-sympodial[b]
	Width/height (mm)	35–40/60–95	Max. 50 basal diameter/1 m[a]	62–135/50–155[c]
	Lateral corallite arrangement/ budding angle	Lateral corallites in 3 rows/40°–60°	Lateral corallites in 2 rows/45°[a]	Lateral corallites in all directions/perpendicular[b]
Corallites	LCD×GCD (mm)	7–13 (9.33)×9–13 (10.33) (axial); 4–8 (6.29)×5–9 (7.47) (1st lateral); 3–5 (4.31)×4–5 (5.16) (2nd lateral)	6–8 (max. 10–12)[d]; 4.5–6.5 (5.6)×5.0–7.5 (6.4)[e]; 8.1–10.5 (axial), 6.2–7.8 (lateral)[f]	6–7 (axial), 5–6×3–9 (lateral)[b]; 4.3–6.7 (5.3)×4.7–7.2 (5.9)[c]
	Height (mm)	8–60 (27.67) (axial); 3–13 (7.00) (1st lateral); 2–4 (2.67) (2nd lateral)	3.5–12.6 (6.9, max. 15–18)[e]	6.6 (2.8–20.7)[c]
Septa	Arrangement	Normal (or irregular Pourtalès plan)	Normal[a] (or irregular Pourtalès plan)[e]	Pourtalès plan[b] (or regular Pourtalès plan)[c]
	Cycle	Hexamerous, 4–5 cycles (axial), 3–4 cycles (lateral)	Hexamerous, 3–4 (mostly 3) cycles[e]	Hexamerous, 4 cycles, some 5 cycles (axial)[g]
Color in living		NA	Red, orange or black[e]; dark green or brown-black[a]	Coenosarc yellow[c]

The number in parentheses for the data of the characters indicates the average.
LCD, lesser calicular diameter; GCD, greater calicular diameter; NA, not available.
[a]Cairns and Zibrowius (1997), [b]Cairns (1994), [c]Ogawa and Takahashi (1995), [d]Nemenzo (1960), [e]Ogawa and Takahashi (1993), [f]Tachikawa (2005), [g]Eguchi (1968).

Dendrophyllia nigrescens Dana, 1846: 387.
Dendrophyllia micranthus: Nemenzo, 1960: 16, Pl. 8, fig. 2.
Tubastraea micrantha: Cairns and Keller, 1993: 282; Ogawa and Takahashi, 1993: 99–100, Pl. 3, figs. 1–6, Pl. 6, figs. 5, 6; Dai and Horng, 2009: 163.
Tubastraea micranthus: Cairns and Zibrowius, 1997: 195; Tachikawa, 2005: 20, Pl. 13, figs. G–K.

Material examined. Korea: 1 ind., Jeju-do: Seogwipo-si, Munseom, 21 Feb 2003, Song JI (EWZS 6422).

Description. Corallum colonial, attached. Growth form dendroid with 1 main trunk and enlarged base, 35–40 mm in width, 60–95 mm in height. Extratentacular budding. Branches from a main trunk absent. One axial corallite erected as a main trunk. Other axial corallites distributed at the basal part of the colony. Lateral corallites developed around the main trunk. Corallites at the basal part of the main trunk scattered irregularly or adjacently. Up to 2nd lateral corallites developed. 1st lateral corallites projected upward at 40°–60° from the main trunk, arranged in 3 rows of directions around the main trunk of the axial corallite. Some 1st lateral corallites sympodially budded from the lower part of the axial corallite. Intercorallite distance between 1st lateral corallites 1–3 mm. Axial corallites cylindrical, 7–13×9–13 mm in calicular diameter (GCD : LCD 1.00–1.29), 8–60 mm in height. 1st lateral corallites cylindrical, 5.23–7.71×5.62–9.33 mm in calicular diameter (GCD : LCD 1.03–1.32), 3–13 mm in height. 2nd lateral corallites cylindrical, 3.60–5.42×4.40–6.38 in calicular diameter (GCD : LCD 1.18–1.22), 2–4 mm in height. Lateral corallites at the lower part of the colony larger in calicular diameter, longer in height than those at the higher part of the colony. Calice elliptical or circular. Columella spongy, elliptical or circular, 4.75×6.56 mm in diameter for axial corallites, 1.43–3.20×1.57–3.91 mm in diameter for 1st lateral corallites, 0.95–1.35×1.26–1.43 mm in diameter for 2nd lateral corallites. Fossa 1–9 mm in depth. Theca synapticulotheca, defined with costae, intercostal striae. Costae granulated, 0.10–0.33 mm in width. Intercostal striae porous, 0.07–0.21 mm in width. Septa irregularly fused or straight, hexamerously arranged in 3–4 cycles for lateral corallites, approximately 4–5 (mostly 4) cycles for axial corallites. Septal faces covered with small spines.

Remarks. The dry specimen examined in this study is worn off in a poor condition, with the tissues being stuck in the skeleton. Hence, the septal arrangement is not clear enough. Nonetheless, the specimen generally agrees with *T. micranthus* in its dendroid growth form, small calicular diameter (generally 6–8 mm) of lateral corallites, and relatively straight septa with a hexamerous arrangement usually in 3–4 cycles (Table 3). In contrast, the 1st lateral corallites

of the specimen in this study are arranged in 3 rows of directions around the main trunk without branches; and the largest axial corallite of this specimen appears to have some more septa in 5 cycles (Table 4). As shown in Table 4, *T. micranthus* is similar to *Dendrophyllia ijimai* in the axial corallite dendroid growth form. However, the former is distinguished from the latter by the absence of the Pourtalès plan or the presence of a normal septal arrangement or the presence of the irregular Pourtalès plan (Ogawa and Takahashi, 1993; Cairns, 1994).

Distribution. Pacific Ocean: Korea (Jeju-do); Japan; Taiwan; Philippines (Mindoro, Sulu Sea, Negros); Indonesia (Savu Sea, Timor); Indo-Pacific; Indian Ocean.

ACKNOWLEDGMENTS

This research was supported by a grant of the Marine Biotechnology Program from the Ministry of Oceans and Fisheries of Korean Government.

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Received December 24, 2016
Revised February 21, 2017
Accepted February 22, 2017