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A new species of the sun coral genus *Tubastraea* (Scleractinia: Dendrophylliidae) from Hong Kong

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Abstract

Tubastraea, commonly known as sun coral, is a genus of brightly coloured azooxanthellate corals in the family Dendrophylliidae. The diversity of this genus is low, with only seven recognized species. Herein, we describe *Tubastraea megacorallita* **sp. nov.** from Hong Kong based on morphological and molecular analyses. This new species exhibits several characteristics of the genus including being colonial, having a rough texture of corallum and no epitheca. It can be distinguished from its congenerics by bigger corallites, and the Pourtalès plan arrangement of its septa. The *rDNA* gene sequences (consisting of *ITS1*, *5.8S*, *ITS2*, *18S* and *28S*) showed 2.45–5.18% divergence from those of its closest relatives, *T. coccinea* and *T. micranthus*.

Key words: scleractinian coral, azooxanthellate, ahermatypic coral, dendrophylliid, South China Sea

Introduction

Dendrophylliidae Gray, 1847 is one of the most diverse scleractinian families, comprising 22 genera and 173 extant species (Hoeksema & Cairns 2020). Traditionally, the taxonomic classification of this family depended heavily on morphological characters related to growth form (solitary or colonial), absence or presence of zooxanthellae (azooxanthellate or zooxanthellate), and skeletal appearance, as well as septal arrangement. In the most comprehensive phylogenetic reconstruction of the Dendrophylliidae, based on morphological traits of 364 extant and fossil specimens, Cairns (2001) analysed ten characters in four categories: gross morphology (colony form, corallum shape, buddying type and corallum attachment), thecal structure (presence or absence of synapticulotheca, epitheca and endotheca), calicular elements (septal arrangement and columella appearance), and the symbiosis with zooxanthellae. He concluded that the family Dendrophylliidae is monophyletic and can be divided into 21 extant genera.

Some scleractinian corals may display intra-specific plasticity in morphological characters (Todd 2008), which highlights the importance of molecular approaches in delineating species within the same genus. In particular, two studies have revisited the systematics of Dendrophylliidae, both with a molecular approach using various mitochondrial and nuclear markers. A study inferring interfamily relationships confirmed it as a well-supported monophyletic scleractinian family composed of shallow to deep-water azooxanthellate and zooxanthellate species (Kitahara *et al*. 2010). Yet, further examination of the systematics within the Dendrophylliidae (Arrigoni *et al*. 2014) revealed polyphyletic relationships in some of the dendrophylliid genera, including *Balanophyllia* Wood, 1844, *Cladopsammia* Lacaze-Duthiers, 1897, *Dendrophyllia* de Blainville, 1830, *Rhizopsammia* Verrill, 1870 and *Turbinaria* Oken,1815. They also noted that the morphological characters used by Cairns (2001) to distinguish dendrophylliid taxa may be insufficient in inferring the evolutionary changes and speciation in this family.

Among the 11 genera examined by Arrigoni *et al*. (2014), *Tubastraea* Lesson, 1830 represented a monophyletic

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clade. The genus is characterized by six characters: 1), colonial coralla firmly attached and encrusting; 2), septa cycles hexamerally arranged and typically inserted with spongy columella; 3), septa not arranged in a Pourtalès plan; 4), corallum with a rough texture; 5), colony developing from a common basal coenosteum by budding, with clear connection among polyps; 6), columella small to moderate in size and lacks an epitheca (Cairns 2001; Cairns & Kitahara 2012). This genus includes seven extant species that are native to the Indo-Pacific region, including *T. aruea* Quoy & Gaimard, 1833, *T. coccinea* Lesson, 1830, *T. diaphana* Dana, 1846, *T. faulkneri* Wells, 1982, *T. floreana* Wells, 1982, *T. micranthus* Ehernberg, 1834 and *T. tagusensis* Wells, 1982.

Little is known about the diversity of ahermatypic scleractinian corals in Hong Kong (Chan *et al*. 2005). Scott (1984) was the first author to document ahermatypic corals of Hong Kong and reported on eight species of Dendrophylliidae and two species of Oculinidae Gray, 1847. A more recent study, based on sampling from two underwater caves, reported 16 species from three families, including 12 species of Dendrophylliidae, one species of Oculinidae and three species of Rhizangiidae d'Orbigny, 1851 (Lam *et al*. 2008). Based on the current taxonomic classification (Hoeksema & Cairns 2020), only five of the reported ahermatypic corals species in Hong Kong belong to *Tubastraea*, including *T. aurea*, *T. coccinea*, *T. diaphana*, *T. faulkneri*, and *T. micranthus.*

During underwater surveys conducted in a study of corallivorous animals in Hong Kong, we discovered three species of coral-eating nudibranchs: *Phestilla fuscostriata* Hu *et al.*, 2020 feeds on *Pavona decussata* (Hu *et al.* 2020a), and *Phestilla goniophaga* Hu *et al.*, 2020 feeds on *Goniopora* (Hu *et al.* 2020b) in shallow water (< 10 m depth); *Phestilla melanobrachia* Bergh, 1874 feeds on *Duncanopsammia peltata* (Esper, 1790) in shallow water, and on the sun corals *Tubastraea, Dendrophyllia* and *Balanophyllia* in deeper water (10–30 m) (Yiu *et al.* 2021). Among these sun corals, we discovered several colonies of *Tubastraea* that do not match the morphological descriptions of earlier recorded species. The present study therefore applies an integrated morphological and molecular approach to describe this new species and determine its phylogenetic relationships with other species of this genus.

Methods

Sample collection. Four colonies of *Tubastraea megacorallita* **sp. nov.** were collected from Breaker reef (22.461°N, 114.420°E) at 17 m water depth by SCUBA. They were preserved in 95% ethanol and deposited in the Tropical Marine Biodiversity Collections of the South China Sea (TMBC), Chinese Academy of Sciences.

Morphological analysis. Photographs of the specimens were taken using an Olympus OM-D EM1markII with a M. Zuiko Digital ED 60mm f2.8 Macro lens. Morphological characters defined by Cairns (2001); Cairns & Kitahara (2012) and Arrigoni *et al.* (2014) were used for species identification. They included whole colony size, corallite size, fossa depth, intercorallite distance and septa arrangement. The size measurements were performed using Coral Point Count with Excel extensions (CPCe) 4.1 (Kohler & Gill 2006) on photographs taken along with a ruler. The following abbreviations were used: GCD, greater calicular diameter; LCD, lesser calicular diameter; S, septa.

DNA extraction and sequencing. Genomic DNA was extracted from the tissues of three specimens (BU-Cni-20-001 to 3) using the CTAB method (Stewart & Via 1993). DNA quantity and purity were checked using a Nano-Drop ND-1000 spectrophotometer (Thermo Fisher Scientific, US). DNA quality was examined using 1% agarose gel electrophoresis. The products were submitted to Novogene (Beijing, China) for commercial library construction and sequencing on an Illumina Novaseq 6000 platform to produce 5 GB paired-end sequencing data with an average read length of 150 bp.

Molecular analysis. Raw sequences were filtered using Trimmomatic v0.38 (Bolger *et al*. 2014) under the following settings: ILLUMINACLIP:TruSeq2-PE.fa:2:30:10 LEADING:5 TRAILING:5 SLIDINGWINDOW:4:15 MINLEN:40. SPAdes v3.13 (Bankevich *et al*. 2012) was used to assemble the sequences, and BLAST+ v2.2.26 was used to extract the scaffold outputs that matched the mitochondrial cytochrome *c* oxidase subunit I (*COI*), the mitochondrial intragenic region between *COI* and *trnM*, *trnM* and The mitochondrial intragenic region between *COI* and *trnM*, *trnM* and the mitochondrial intragenic region between *trnM* and the ribosomal subunit (*IGR*), *ITS1*, *5.8S, ITS2* and a portion of *18S* and *28S* (*rDNA*) genes from a query file with data from the corresponding gene sequences of *Tubastraea* sp. 3 downloaded from NCBI's GenBank. *Goniopora djiboutiensis* Vaughan, 1907 (Poritidae) was chosen as the outgroup. The corresponding gene sequences from *G. djiboutiensis*, as well as members of the family Dendrophylliidae (Capel *et al*. 2020) were downloaded from GenBank (Table S1) for determination of the phylogenetic position of the collected specimens. Alignments of the three genes were conducted separately with MUSCLE (Edgar 2004) and trimmed manually to 601 bp for *COI*, 448 bp for *IGR* and 632 bp for *rDNA* using Unipro UGENE v.36.0 (Okonechnikov *et al*. 2012), then concatenated using SequenceMatrix v.1.7.8 (Vaidya *et al*. 2011). Phylogenetic analyses were conducted using both Maximum Likelihood (ML) and Bayesian Inference (BI) methods as in Xu *et al.* (2019). For ML, the website version of IQ-Tree (Nguyen *et al*. 2015, http://iqtree.cibiv.univie.ac.at/) was adopted to conduct the partitioned reconstruction with 1,500 ultrafast bootstrap pseudoreplicates and random starting trees (Hoang *et al*. 2017). ModelTest (Kalyaanamoorthy *et al*. 2017) in IQ-Tree was applied for each partition of the concatenated sequences, which detected TPM3u+F+I as the best model for *COI*, HKY+F+G4 for *IGS* and K2P+I+G4 for *rDNA* based on the Bayesian Information Criterion. BI analysis was performed using MrBayes v.3.2.7a (Ronquist & Huelsenbeck 2003) with four Metropolis-coupled Markov Chain Monte Carlo applied to 10 million generations, sampled at every 10 generations with a 25% burn-in. Since the best models detected for the concatenated dataset by ModelTest were not available in MrBayes, they were substituted by the closest over-parameterized models (Huelsenbeck & Rannala 2004): GTR+I+G for *COI*, HKY+I+G for *IGR* and K2P+I+G for *rDNA*. The phylogenetic trees were visualized with the 'ggplot2', 'ape' and 'ggtree' packages (Wickham 2016; Yu *et al*. 2017; Paradis & Schliep 2019) in RStudio 1.2.5019 and annotated by Photoshop CC 2018. Pairwise genetic distances for the *COI*, *IGR* and *rDNA* genes were estimated using MEGA X (Kumar *et al*. 2018 separately based on the nucleotide substitution type, *p*-distance method with 10,000 pseudoreplicates for variance estimation. Rates among sites were assumed to be gamma distributed with invariant sites (G+I) and the gamma parameter was set to four.

Results

Systematic account

Class ANTHOZOA Ehrenberg, 1834

Order SCLERACTINIA Bourne, 1900

Family DENDROPHYLLIIDAE Gray, 1847

Genus *Tubastraea* Lesson, 1830

Diagnosis of genus *Tubastraea* (emended after Cairns 2001 and Cairns & Kitahara 2012)

Colonial coralla firmly attached and encrusting; septa cycles hexamerally arranged and typically inserted with spongy columella; septa arranged /not arranged in a Pourtalès plan; corallum with a rough texture; colony developing from a common basal coenosteum by budding, with clear connection among polyps; columella small to moderate in size and lacks an epitheca.

***Tubastraea megacorallita* sp. nov.**

http://zoobank.org/NomenclaturalActs/fdcf7eaf-110d-40f6-b042-d39037e883d2

Synonymy

Tubastraea coccinea—Scott 1984:40, fig.48.
Balanophyllia ponderosa—Lam *et al.* 2008:735, figs. 1C-D.
Tubastraea sp. 3—Arrigoni *et al.* 2014:678, figs. 11M-O.
Tubastraea tenuilamellosa—Rowlett 2020:508.

Materials examined. Holotype: TMBC030850, colony with 14 corallites, 62 mm in length and 25 mm in height. Paratypes: TMBC030851, colony with 11 corallites, 51 mm in length and 24 mm in height; TMBC030852, colony with 9 corallites, 42 mm in length and 23 mm in height; TMBC030853, colony with 4 corallites, 16 mm in length and 11 mm in height.

Type locality. Breaker reef (22.461°N, 114.420°E), Hong Kong.

Etymology. *Tubastraea megacorallita* **sp. nov.** has relatively large corallites when compared with its congeneric species. The species epithet reflects this morphological character.

Geographical distribution. Currently only known in Hong Kong (this study) and Kii-Nagashima, Japan (Arrigoni *et al.* 2014).

Habitat. Exposed sites with moderate current, rocky substrate, at 10–25 m water depth.

Description. When alive (Fig 1a), the tissue outside epithecal wall is light orange or pink and corallite bright red, and the tentacles are yellow and translucent. The colonies are phaceloid with each of the long corallite having its own wall. The corallites are formed by extratentacular budding (Fig 1b), consisting of 3 to 14 corallites. They vary between 16–62 mm in length and 11–25 mm in height. The corallites are elliptical (8–25 mm in GCD and 6.5–19 mm in LCD) with a thick wall. The total number of septa varies from 34 to 92, with 10–16 of the septa fused with columella (Table 1). The number of septa increases as the corallites become bigger. The septa are hexamerously arranged, containing 5 cycles, the last cycle incomplete, with the sizes increasing from the inner to the outer as $S_1=S_2>S_3>S_4=S_5$. The septa are usually arranged in a Pourtalès plan with the axial edges of pairs of higher cycle septa bending in front of and uniting before their adjacent lower cycle septum (Fig. 1c). The septa extend from the edge, curving down to the columella. The columella (Fig.1d) consists of a spongy network (2–10 mm in GCD and 1–4 mm in LCD). The depth of the fossa ranges from 2.5 mm to 10 mm. The costae are granulated and the intercostal striae are porous (Fig.1e)

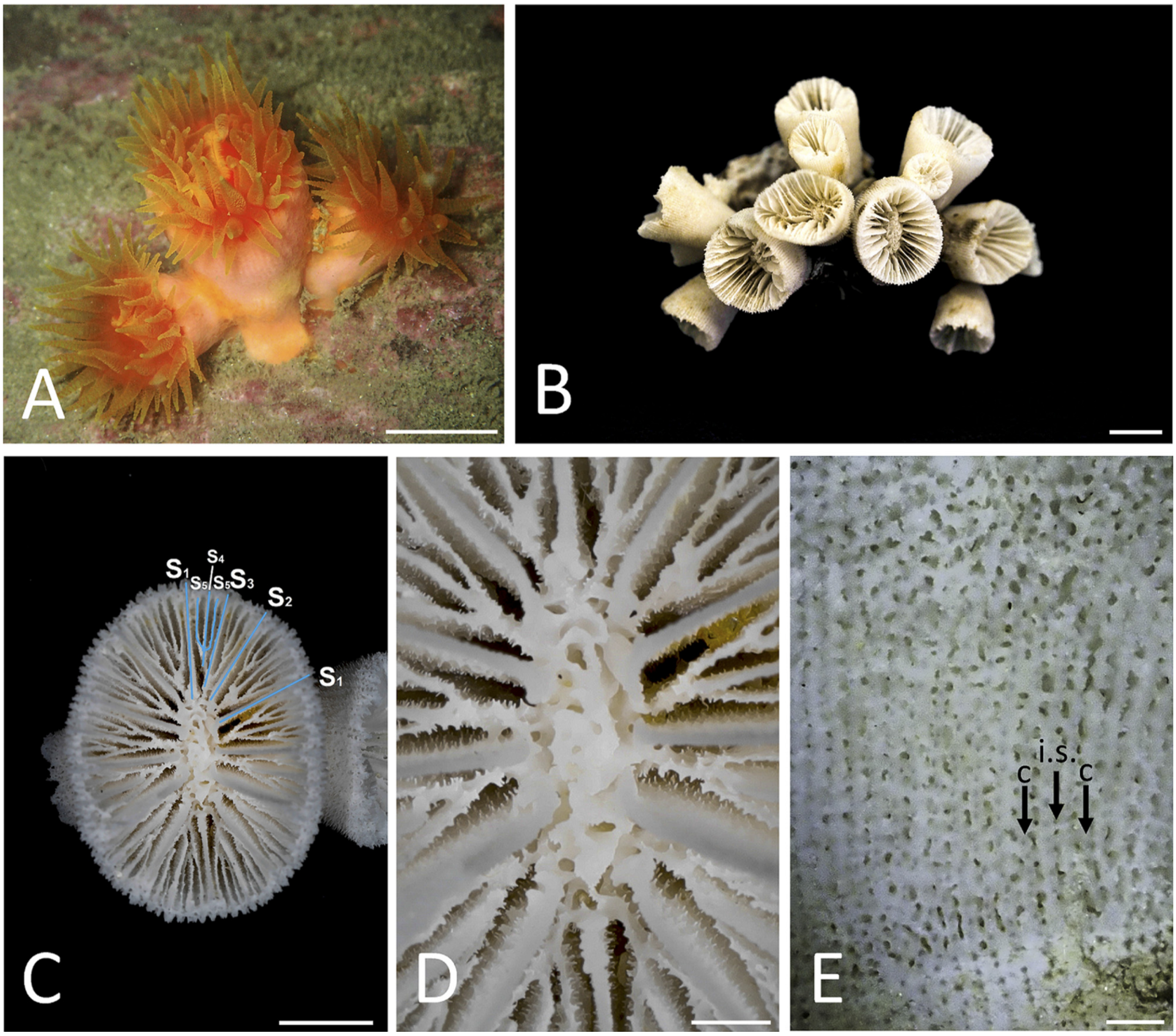

FIGURE 1. *Tubastraea megacorallita.* **sp. nov.** A: A living specimen in the field; B: Skeleton of a specimen with tissues removed (TMBC030850); C: a corallite (TMBC030853); D: Fossa (TMBC030853); E: Costae (c) and Intercostal striae (i.s.) (TMBC030853). Scale bar: A–B: 1 cm; C: 5 mm; D–E: 1 mm.

Taxonomic remarks. Our specimens belong to the genus *Tubastraea* because it shares seven characters with congeneric species (Cairns & Kitahara 2012): 1) corallum is colonial; 2), corallum is firmly attached; 3), corallum is encrusting; 4), multiple septa cycles are hexamerally arranged and spongy columella; 5), texture of corallum is rough; 6), number of coralla increases by budding from a common basal coenosteum, the connection among polyps is quite evident, and the septa are normally inserted; 7), columella is moderate to small in size and lacks epitheca. However, it is the only species of *Tubastraea* in which the septa are arranged in a Pourtalès plan.

Morphologically, *Tubastraea megacorallita* **sp. nov.** can be easily distinguished from its congeneric species. It has five septal cycles and the septa are usually arranged in a Pourtalès plan, whereas the other seven species have only three to four septal cycles without a Pourtalès plan. Although *T. megacorallita* **sp. nov.** is most closely related to *T. coccinea* and *T. micranthus* in our molecular phylogenetic analysis, they differ substantially in corallite morphology (Table 1). The corallites of *T. megacorallita* **sp. nov.** are larger than those of *T. coccinea* and *T. micranthus*. *Tubastraea coccinea* and *T. micranthus* have four and three septal cycles, respectively but *T. megacorallita* **sp. nov.** has five.

Molecular analysis. Three gene sequences were successfully obtained from each of the three specimens. Alignment and concatenation resulted in a dataset of 1.683 bp (*COI*: 601 bp, *IGR*: 450 bp, *rDNA*: 632 bp). Within the three partitions, only *rDNA* has adequate phylogenetic signal for species distinction. The uncorrected *p*-distances were 0% for all the three genes among the three individuals of *T. megacoralllia* **sp. nov.** collected from Hong Kong in this study (Table 2). With a *p*-distance of only 0 for *COI*, 0 for *IGR*, and 0.21 or 0.41% for *rDNA* (KI2, KI3 respectively), *Tubastraea* sp. 3. – an undescribed species collected from Kii-Nagashima, Japan (Arrigoni *et al.* 2014) – is considered to be conspecific to *T. megacorallita* **sp. nov.** This new species exhibits 0–0.83%, 0–0.67% and 2.45–6.91% *p*-distance with other congeneric species in the *COI*, *IGR* and *rDNA* genes, respectively. These distances were equivalent or larger than the interspecific distances among *T. coccinea*, *T. micranthus* and *Tubstreaea* sp. 2, which supports the recognition of *T. megacorallita* as a new species.

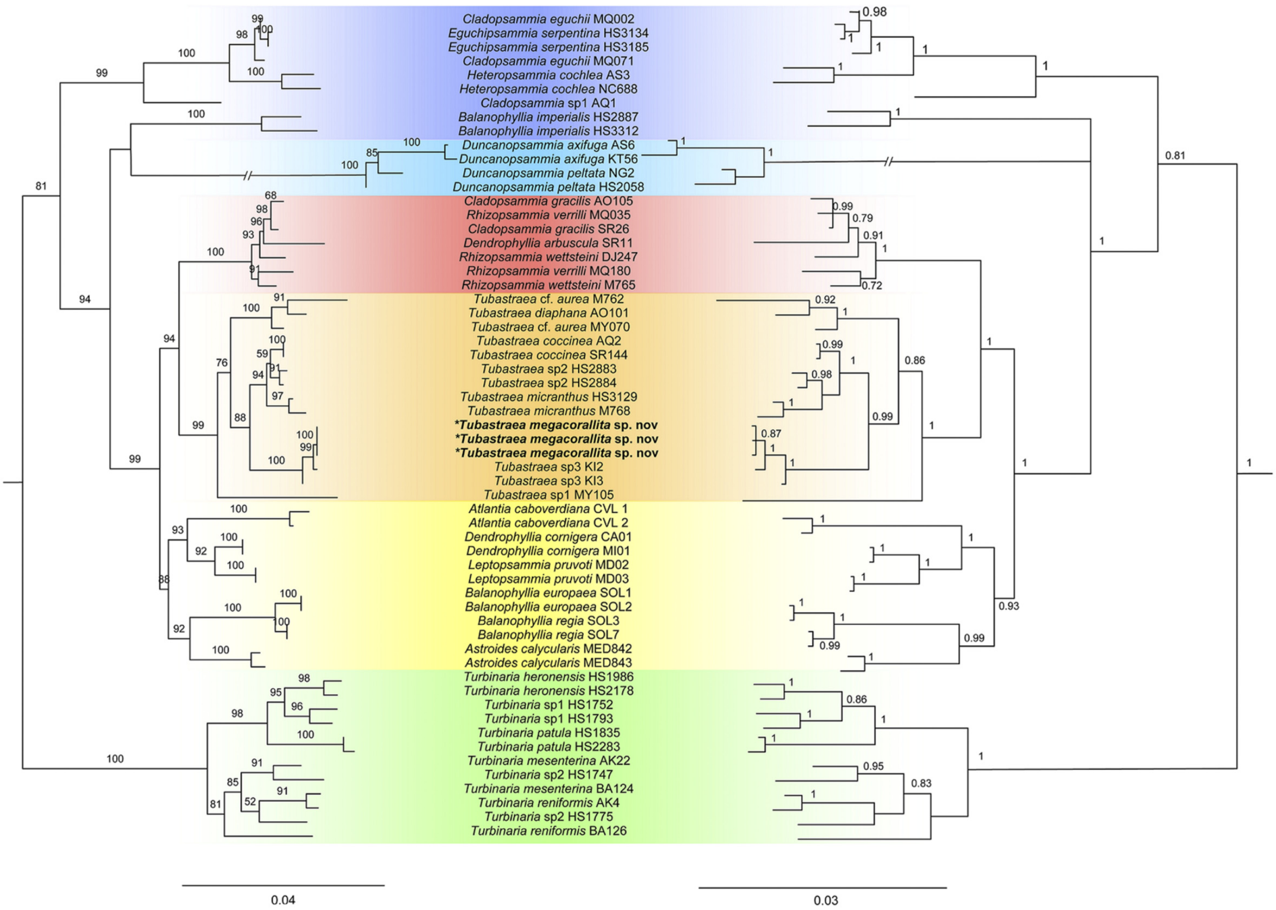

FIGURE 2. Phylogenetic trees of the concatenated *COI/IGR/rDNA* sequence dataset constructed using the Maximum Likelihood (left) and Bayesian Inference (right) method. Maximum Likelihood bootstrap values >50 and Bayesian Inference posterior probability values > 0.7 are shown in the nodes. Specimens used in this study are denoted by an asterisk.

TABLE 1. Comparison of morphological characters between *Tubastraea megacorallita*. **sp. nov.** and other *Tubastraea* spp.

	Characters	*T. aurea*[a,b]	*T. coccinea*[c,d,e,f]	*T. diaphana*[e,h]	*T. faulkner*[d,h,i]
Growth form		Plocoid	Plocoid	Dendroid/Phaceloid	Plocoid
Intercorallite distance			Closely spaced		Closely/widely spaced
Corallites	Shape	Elliptical	Circular	Circular	Circular
	LCD x GCD (mm)	12.0 x10.0	10.0-13.0	6.0-11.0	5.2-7.8/8.0-13.0
Columella	LCD x GCD (mm)/Size	2.0x1.0 -5.0x2.0	Large		Large
Fossa	Depth(mm)	6.0-7.0	Moderately deep	Deep	Deep and spongy/Shallow
Septa	Arrangement	Normal	Normal	Normal	Normal
	Total number		Up to 48		48+
	No. of septa fused with columella		12		
	Number of cycles	4 cycles	4 cycles	4 cycles	4 cycles
	Size		$S_1=S_2>S_4>S_3$	$S_1>S_2>>S_3>S_4$; $S_1=S_2>S_4=S_3$	$S_1>S_2>S_4>S_3$
	Fusion		S_4 united with S_3		
	Colour in living	Orangish red		Green-brown	Orange with yellow tentacles

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TABLE 1. (Continued)

	Characters	*T. floreana*[h,i]	*T. megacorallita* **sp. nov.**	*T. micranthus*[e,j,k]	*T. tagusensis*[d,i]
Growth form		Phaceloid	Phaceloid	Dendroid/Branching uniplanar	Phaceloid
Intercorallite distance		Closely/widely spaced	Closely/widely spaced		Closely spaced
Corallites	Shape	Cylindrical	Elliptical	Circular	Cylindrical
	LCD x GCD (mm)	4.0-6.0	6.3-19.1 x 8.0-24.6	4.5-6.5 x 5.0-7.5	<10.0
Columella	LCD x GCD (mm)/Size	Rudimentary	0.9-3.7 x 1.9-10.1	Rudimentary	Rudimentary
Fossa	Depth (mm)	4.0-5.0; moderately deep	2.5-18.1	4.0-9.0	Deep
Septa	Arrangement	Normal	Pourtalès plan	Normal	Normal
	Total number	24	34-92		24/48
	No. of septa fused with columella		10-26		
	Number of cycles	3 cycles	5 cycles	3 cycles	3 or 4 cycles
	Size	S_1=S_2>S_3	S_1=S_2>S_3>S_4=S_5	S_1>S_2>>S_3	S_1=S_2>S_3>S_4; S_1=S_2=S_3>S_4
	Fusion	No	S_5 fused with S_4 and S_3		No
	Colour in living	Corallum: white; Polyps: bright pink	Orange, reddish, yellow	Dark green, brown black, red, orange	Polyps: lemon-yellow with red peristomes, pale red-violet, pale red violet with yellowish coenosarc

[a]Song (1982), [b]Scott (1984), [c]Wells (1983), [d]Cairns (1991), [e]Cairns & Zibrowius (1997), [f]Cairns (1994), [h]Lam *et al*. (2008), [i]Wells (1982), [j]Nemenzo (1960), [k]Ogawa & Takahashi (1993)

TABLE 2. Uncorrected *COI*/*IGR*/*rDNA* *p*-distances (%) calculated based on individual gene of the seven available *Tubastraea* species in the NCBI and the sequences of specimens from this study (in bold).

		1	2	3	4	5	6	7	8	9	10	11
1	*Tubastraea* sp. 1 (MY105)											
2	*Tubastraea* cf. *aurea* (M762)	1.16/0.45/7.27										
3	***Tubastraea megacorallita* sp. nov. (TMBC030850)**	0.83/0.45/5.64	0.33/0.45/4.76									
4	***Tubastraea megacorallita* sp. nov. (TMBC030851)**	0.83/0.45/6.87	0.33/0.45/6.91	0/0/0								
5	***Tubastraea megacorallita* sp. nov. (TMBC030852)**	0.83/0.45/6.87	0.33/0.45/6.91	0/0/0	0/0/0							
6	*Tubastraea coccinea* (AQ2)	0.83/0.45/4.95	0.33/0.45/5.87	0/0/2.45	0/0/3.9	0/0/3.9						
7	*Tubastraea micranthus* (HS3129)	0.83/0.45/5.57	0.33/0.45/6.66	0/0/4.39	0/0/5.18	0/0/5.18	0/0/1.67					
8	*Tubastraea* sp. 2 (HS2883)	0.83/0.45/5.13	0.33/0.45/5.90	0/0/2.63	0/0/4.98	0/0/4.98	0/0/2.11	0/0/1.37				
9	*Tubastraea* sp. 3 (KI2)	0.83/0.45/6.23	0.33/0.45/6.27	0/0/0.18	0/0/0.21	0/0/0.21	0/0/3.93	0/0/4.51	0/0/5.04			
10	*Tubastraea* sp. 3 (KI3)	0.83/0.45/5.88	0.33/0.45/6.54	0/0/0	0/0/0.41	0/0/0.41	0/0/3.49	0/0/3.99	0/0/4.41	0/0/0.41		
11	*Tubastraea diaphana* (AO101)	-/0.67/5.50	-/0.22/3.50	-/0.67/2.78	-/0.67/3.59	-/0.67/3.59	-/0.67/3.50	-/0.67/4.57	-/0.67/3.57	-/0.67/3.32	-/0.67/3.52	

The ML and BI trees exhibited a very similar topology. Both the ML and BI trees showed that the genus *Tubastraea* formed a monophyletic clade within Dendrophylliidae (Fig. 2). Among the seven species of *Tubastraea* used in this analysis, *T. megacoralllia* **sp. nov.** was nested among the other species and was sister to *Tubastraea* sp. 3 K12, an undescribed species from Kii-Nagashima, Japan (Arrigoni *et al*. 2014). Together, they formed a clade that was sister to a clade containing *T. coccinea*, *T. micranthus* and *Tubatraea* sp. 2. However, it was not possible to determine which of these species is most closely related to the clade consisting of *T. megacorallita* **sp. nov.** and *Tubastraea* sp. 3. Other species of *Tubastraea* are more distantly related to *T. megacorallita* **sp. nov.**

Discussion

Among the eight recognized *Tubasreaea* species, *T. megacorallita* **sp. nov.** is the only species having corallites with up to five septal cycles in a Pourtalès plan and it has the biggest corallites. In all other *Tubastraea* species the septa are normally arranged and does not show a Pourtalès plan (Cairns 2001). This result supports our revision of the diagnosis of the genus by removing "normally arranged septa" as one of the defining characters of *Tubastraea*. We observed that the Pourtalès plan is absent in small corallites of *Tubastraea megacorallita* **sp. nov.**, but it is usually present in corallites at least 17 mm x 15 mm (GCD x LCD). Since the Pourtalès Plan has occurred several times in the phylogeny of Dendrophylliidae (Cairns 2001) and it may be absent in juvenile corals, further studies are needed to determine the value of this character in the taxonomy of the family.

Tubastraea megacorallita **sp. nov.** is the second species in this genus that has elliptical-shaped corallites. The other species that has elliptical corallites is *T. aurea*. However, the colonies of *T. megacorallita* **sp. nov.** are phaceloid while those of *T. aurea* are plocoid. Based on molecular phylogenetic results, *T. megacorallita* **sp. nov.** is most closely related to *T. coccinea* and *T. micranthus*. However, their morphological characters are significant different in that the colonies of *T. micanthus* are tree-like with the corallites forming long branches, and this character is unique in this genus (Cairns & Zibrowius 1997). The colonies of *T. megacorallita* **sp. nov.** are phaceloid, formed by very few corallites. *Tubastaea coccinea* is plocoid with closely spaced corallites that have four septal cycles.

In the previous records of ahermatypic corals in Hong Kong, *T. megacorallita* **sp. nov.** might have been misidentified as *T. coccinea* by Scott (1984) because the specimen illustrated in this book is phaceloid, and the corallites are widely spaced and elliptical with five septal cycles. Lam *et al.* (2008) reclassified this species as *Balanophyllia ponderosa*. However, our molecular and morphological analyses supported the recognition of this new species. Although there was no clear divergence in the *COI* and *IGR* genes among *T. aurea, T. coccinea, T. micranthus, T. diaphana and Tubastraea* spp. 1–3, these two genes have been shown to lack phylogenetic signal for interspecies comparison in cnidarians (Shearer & Coffroth 2008). The *rDNA* sequences of *T. megacorallita* **sp. nov.** exhibit 2.45–5.18% divergence with its closely related species, which are bigger than or equivalent to the interspecific divergence between other species of this genus.

Our field observation shows that *T. megacorallita* **sp. nov.** appears to have a narrower depth range (10–25 m) than *T. coccinea*, which locally occurs from the surface to bottom (0–25 m) and this is consistent with the wide depth range of this species (0–110 m) reported by Cairns (1994) from elsewhere. The geographical distribution of *T. megacorallita* **sp. nov.** is unknown, but according to the gene sequences of a specimen collected from Kii-Nagashima, Japan (Arrigoni *et al.* 2014), this species should also be distributed at least in the sub-tropical to temperate regions of the western Pacific.

The nudibranch *Phestilla melanobrachia* Bergh, 1874 has been found to feed on sun corals, including *T. aurea, T. coccinea, T. diaphana,* and *T. micranthus* in various Indo-Pacific localities (Edmondson 1933; Harris 1968; Faucci *et al.* 2007; Fritts-Penniman *et al*. 2020). In Hong Kong, *P. melanobrachia* is a common predator of *T. coccinea, T. diaphana*, and *T. megacorallita* **sp. nov.** (Yiu *et al.* 2021). In addition, the gastropod *Coralliophila costularis* (Lamarck, 1816) was found to feed on *T. megacorallita* **sp. nov.**, and *T. diaphana*. *Epidendrium* sp. was also found to feed on *T. coccinea* during an ecological survey (Fig. 3), but it is not sure whether they are common predators of *T. megacorallita* **sp. nov.** Based on previous host records and distribution range, this snail species could be either *Epidendrium aureum* Gittenberger & Gittenberger 2005 or *E. sordidum* Gittenberger & Gittenberger 2005 (Gittenberger & Gittenberger 2005, Gittenberger & Hoeksema 2013).

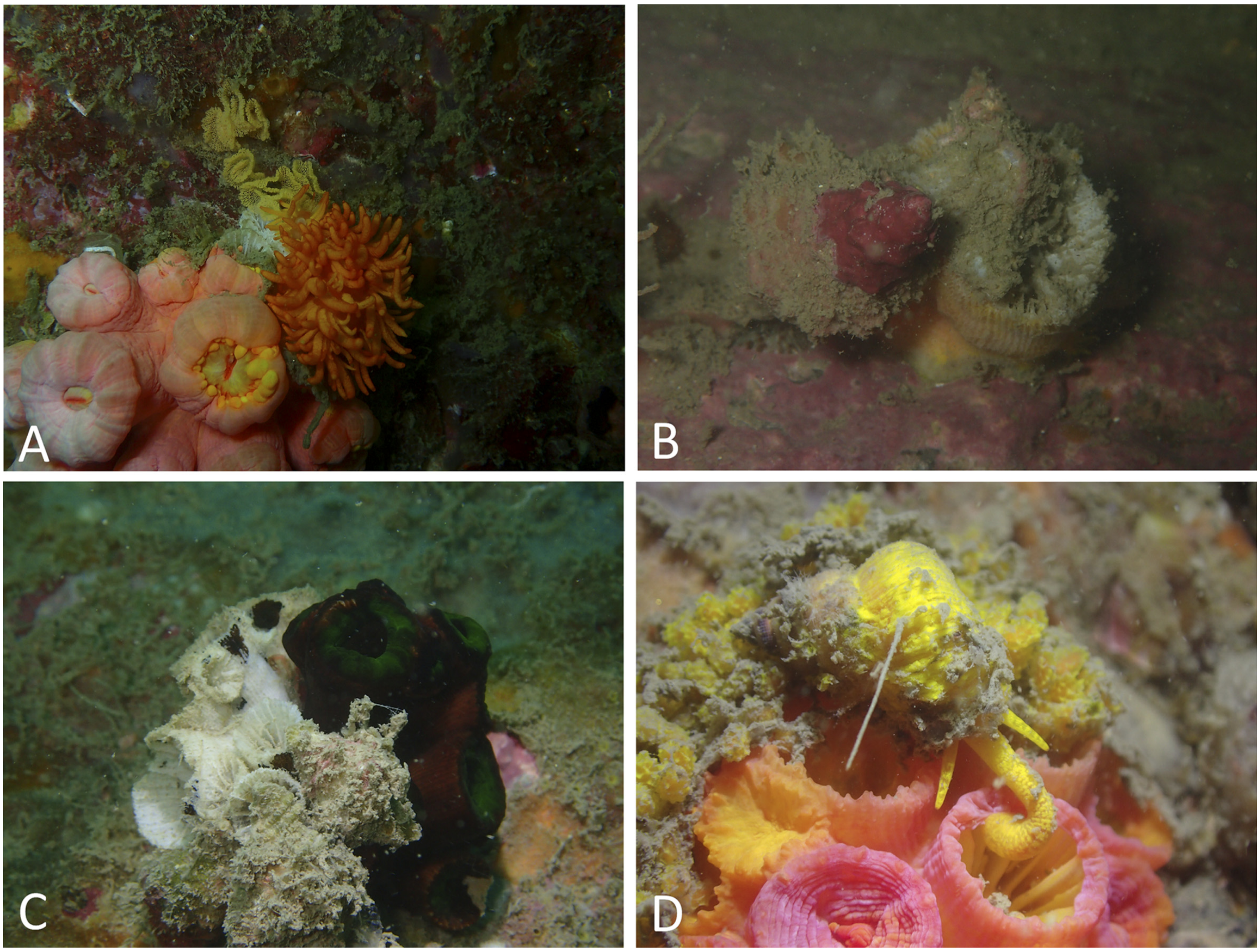

FIGURE 3. Possible predators of *Tubastraea megacorallita* **sp. nov.** A: an individual of *Phestilla melanobrachia* feeding on *T. coccinea*; also shown are egg masses (yellow) of the nudibranch; B: an individual of *Coralliophila costularis* feeding on a colony of *T. megacorallita* **sp. nov.**; C: three individuals of *Coralliophila costularis* feeding on a colony of *Tubastraea diaphana.* D: an individual of *Epidendrium* sp. feeding on a colony of *T. coccinea.*

Key to species of *Tubastraea*

1a.	Colony branching uniplanar	*T. micranthus*
1b.	Colony not branching uniplanar	2
2a.	Colony plocoid	3
2b.	Colony non-plocoid	4
3a.	Corallite elliptical	*T. aurea*
3b.	Corallite non-elliptical	5
4a.	Corallite phaceloid	6
4b.	Corallite non-phaceloid	*T. diaphana*
5a.	Corallite with moderately deep fossa and up to 48 septa	*T. coccinea*
5b.	Corallite with deep and spongy/shallow fossa and more than 48 septa	*T. faulkneri*
6a.	Septal arranged in a Pourtalès plan	*T. megacorallita* **sp. nov.**
6b.	Septa arranged normally	7
7a.	Corallite with moderately deep fossa and 3 septal cycles	*T. floreana*
7b.	Corallite with deep fossa and 3 or 4 septal cycles	*T. tagusensis*

Conclusions

We described *Tubastraea megacorallita* **sp. nov.** based on molecular and morphological analyses. Like other species of sun corals in Hong Kong, this new azooxanthellate species is distributed in the deeper waters, and is not co-occurring with local zooxanthellate scleractinian corals, such as the reef-building species *Pavona decussata*, *Porites lutea* and *Platygyra carnosa* (Yeung *et al.* 2021). This species is unique among *Tubastraea* spp. in that its septa are arranged in a Pourtalès plan. In eastern Hong Kong waters, it is distributed at depths of 10–25 m. This species may be widely distributed in the tropical and subtropical Western Pacific. The nudibranch *Phestilla melanobrachia* is a common predator of *T. megacorallita* **sp. nov.** In deeper water, this nudibranch has an orange morph and a dark-green morph. But in shallower water where this nudribranch feeds on *Duncanopsammia peltata*, its body and cerata are beige (Yiu *et al.* 2021). The snails *Coralliophila costularis* and *Epidendrium* sp. are potential predators of this new species of sun coral.

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Authors Contribution

JWQ initiated and oversaw the study, and revised the manuscript. SKFY and SSWC conducted the sampling, morphological and molecular analyses, and drafted the manuscript.

Competing Interests

SKFY, SSWC and JWQ declare they have no conflict of interest.

Consent for Publication

All of the authors agreed to publish the paper.

Ethics approval consent to participate

All relevant government guidelines for collection and handling of samples have been followed.

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TABLE S1. GenBank accession numbers of the sequences used in phylogeny reconstruction and species delimitation retrieved from NCBI. Sequences of specimens from this study are in bold and sequences used in pair-wise distance calculations are in asterisks (*).

Species	Locality	Identification #	Accession numbers		
			COI	*IGR*	*rDNA*
Family: Dendrophylliidae					
***Tubastraea megacorallita* sp. nov. (TMBC030850)**	**Hong Kong**	**-**	**MW411803**	**MW419904**	**MW415889**
***Tubastraea megacorallita* sp. nov. (TMBC030851)**	**Hong Kong**	**-**	**MW411804**	**MW419905**	**MW415890**
***Tubastraea megacorallita* sp. nov. (TMBC030852)**	**Hong Kong**	**-**	**MW411805**	**MW419906**	**MW415891**
Tubastraea sp. 3*	Japan	KI2	HG965355	HG965291	HG965423
Tubastraea sp. 3*	Japan	KI3	HG965356	HG965292	HG965424
Astroides calycularis	Mediterranean Sea	MED842	HG965307	HG965239	HG965371
Astroides calycularis	Mediterranean Sea	MED843	HG965308	HG965240	HG965372
Atlantia caboverdiana	Cape Verde	CVL-1	MN414205	MN414213	MN412646
Atlantia caboverdiana	Cape Verde	CVL-2	MN414206	MN414214	MN412647
Balanophyllia (*Balanophyllia*) *europaea*	Mediterranean Sea	SOL1	HG965309	HG965241	HG965373
Balanophyllia (*Balanophyllia*) *europaea*	Mediterranean Sea	SOL2	HG965310	HG965242	HG965374
Balanophyllia (*Eupsammia*) *imperialis*	New Caledonia	HS3312	HG965312	HG965244	HG965376
Balanophyllia (*Eupsammia*) *imperialis*	New Caledonia	HS2887	HG965313	HG965245	HG965377
Balanophyllia (*Balanophyllia*) *regia*	Mediterranean Sea	SOL3	HG965314	HG965246	HG965378
Balanophyllia (*Balanophyllia*) *regia*	Mediterranean Sea	SOL7	HG965315	HG965247	HG965379
Cladopsammia sp. 1	Japan	AQ1	HG965316	HG965248	HG965380
Cladopsammia eguchii	Marquesas, French Polynesia	MQ002	HG965317	HG965249	HG965381
Cladopsammia eguchii	Marquesas, French Polynesia	MQ071	HG965318	HG965250	HG965382
Cladopsammia gracilis	Japan	AO105	-	HG965252	HG965384
Cladopsammia gracilis	Japan	SR26	HG965320	HG965253	HG965385
Dendrophyllia arbuscula	Japan	SR11	HG965321	HG965254	HG965386
Dendrophyllia cornigera	Mediterranean Sea	CA01	HG965322	HG965255	HG965387

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TABLE S1. (Continued)

Species	Locality	Identification #	Accession numbers		
			COI	*IGR*	*rDNA*
Dendrophyllia cornigera	Mediterranean Sea	MI01	HG965323	HG965256	HG965388
Duncanopsammia axifuga	Australia	AS6	HG965325	HG965258	HG965390
Duncanopsammia axifuga	Australia	KT56	HG965326	HG965259	HG965391
Eguchipsammia serpentina	New Caledonia	HS3134	HG965327	HG965260	HG965392
Eguchipsammia serpentina	New Caledonia	HS3185	HG965328	HG965261	HG965393
Heteropsammia cochlea	Australia	AS3	HG965329	HG965262	HG965394
Heteropsammia cochlea	New Caledonia	NC688	HG965330	HG965263	HG965395
Leptopsammia pruvoti	Mediterranean Sea	MD02	HG965332	HG965265	HG965397
Leptopsammia pruvoti	Mediterranean Sea	MD03	HG965333	HG965266	HG965398
Rhizopsammia verrilli	Marquesas, French Polynesia	MQ035	HG965334	HG965268	HG965400
Rhizopsammia verrilli	Marquesas, French Polynesia	MQ180	HG965335	HG965269	HG965401
Rhizopsammia wettsteini	Djibouti	DJ247	HG965337	HG965271	HG965403
Rhizopsammia wettsteini	Maldives	M765	HG965338	HG965272	HG965404
Tubastraea cf. *aurea**	Maldives	M762	HG965341	HG965275	HG965407
Tubastraea cf. *aurea*	Mayotte Island	MY070	HG965342	HG965276	HG965408
*Tubastraea coccinea**	Japan	AQ2	HG965344	HG965278	HG965410
Tubastraea coccinea	Japan	SR144	HG965345	HG965279	HG965411
*Tubastraea diaphana**	Japan	AO101	-	HG965281	HG965413
*Tubastraea micranthus**	New Caledonia	HS3129	HG965347	HG965283	HG965415
Tubastraea micranthus	Maldives	M768	HG965348	HG965284	HG965416
Tubastraea sp. 1*	Mayotte Island	MY105	HG965351	HG965287	HG965419
Tubastraea sp. 2*	New Caledonia	HS2883	HG965352	HG965288	HG965420
Tubastraea sp. 2	New Caledonia	HS2884	HG965353	HG965289	HG965421

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TABLE S1. (Continued)

Species	Locality	Identification #	Accession numbers		
			COI	***IGR***	***rDNA***
Turbinaria heronensis	New Caledonia	HS1986	HG965357	HG965293	HG965425
Turbinaria heronensis	New Caledonia	HS2178	HG965358	HG965294	HG965426
Turbinaria mesenterina	Japan	AK22	HG965359	HG965295	HG965427
Turbinaria mesenterina	Yemen	BA124	HG965360	HG965296	HG965428
Turbinaria patula	New Caledonia	HS2283	HG965361	HG965297	HG965429
Turbinaria patula	New Caledonia	HS1835	HG965362	HG965298	HG965430
Duncanopsammia peltata	New Caledonia	HS2058	HG965363	HG965299	HG965431
Duncanopsammia peltata	Japan	NG2	HG965364	HG965300	HG965432
Turbinaria reniformis	Japan	AK4	HG965365	HG965301	HG965433
Turbinaria reniformis	Yemen	BA126	HG965366	HG965302	HG965434
Turbinaria sp. 1	New Caledonia	HS1752	HG965367	HG965303	HG965435
Turbinaria sp. 1	New Caledonia	HS1793	HG965368	HG965304	HG965436
Turbinaria sp. 2	New Caledonia	HS1747	HG965369	HG965305	HG965437
Turbinaria sp. 2	New Caledonia	HS1775	HG965370	HG965306	HG965438
Family Poritidae					
Goniopora djiboutiensis	-	-	MH746816	MH746816	AB748712