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

Anim. Syst. Evol. Divers. Vol. 39, No. 2: 61-66, April 2023
https://doi.org/10.5635/ASED.2023.39.2.060

A New Record of Solitary Coral, *Paracyathus rotundatus* (Anthozoa: Scleractinia: Caryophylliidae), from Korea

Su-Hwan Sim[1], Hyo-Jin Yu[2], Sang-Hoon Park[2], In-Young Cho[3], Won-Gi Min[1], Sung-Jin Hwang[2,*]

[1]Ulleungdo-Dokdo Ocean Research Station, Korea Institute of Ocean Science & Technology, Ulleung 40205, Korea
[2]Department of Life Science, Woosuk University, Jincheon 27841, Korea
[3]National Marine Biodiversity Institute of Korea, Seocheon 33662, Korea

ABSTRACT

Through a taxonomic study on solitary corals collected from subtidal zones of South and East Seas from 2019 to 2022, *Paracyathus rotundatus*, an unrecorded species belonging to family Caryophylliidae, is newly added to the anthozoan fauna of Korea. In addition, comparing partial 16S rRNA sequences with a length of 269 bp according to color variation clarified that there were no sequence differences among specimens with color variation, indicating that the color variation is due to intraspecific variation. As a result of this study, a total of 7 genera and 8 species belonging to the Caryophylliidae family have been reported in Korean waters so far.

Keywords: solitary caryophyllid, azooxanthellate, Dokdo, taxonomy, Korean fauna

INTRODUCTION

The genus *Paracyathus* Milne Edwards and Haime, 1848 belonging to family Caryophylliidae Dana, 1846 was established with type species *Paracyathus procumbens* Milne Edwards and Haime, 1848 from a fossil record only (Milne Edwards and Haime, 1848). A total of 44 extant genera and 27 extinct genera are now known in the family Caryophylliidae (Hoeksema and Cairns, 2022). In Korea, a total of 7 species and 6 genera (*Caryophyllia* Lamarck, 1801; *Crispatotrochus* Tenison-Woods, 1878; *Goniocorella* Yabe and Eguchi, 1932; *Heterocyathus* Milne Edwards and Haime, 1848; *Phyllangia* Milne Edwards and Haime, 1848; *Stephanocyathus* Seguenza, 1864) have been reported so far (Song, 1982, 1991; Choi and Song, 2015).

Paracyathus can be distinguished from other caryophyliids by its solitary and firmly fixed form, granular theca, papillose columella, and having pali before septa except the last cycle (Cairns and Kitahara, 2012). Up to now, 26 valid species (excluding 28 extinct species) have been accepted in the genus *Paracyathus* (Hoeksema and Cairns, 2022). These species have been found in Atlantic, Indian, and Pacific Oceans at different depths ranging from shallow to deep waters to depths up to 1,260 m (Verrill, 1866; Duncan, 1876, 1889; Lindström, 1877; Alcock, 1893; Cairns, 1994, 2004; Cairns and Chapman, 2001; Altuna and Ríos, 2014; Singarayan and Rethnaraj, 2016). Most of them are reported to inhabit the Indo-Pacific waters, with only two species living in the Atlantic Ocean (Lindström, 1877; Cairns and Chapman, 2001; Cairns, 2004). In the study of scleractinians in the temperate North Pacific by Cairns (1994), the proportion of common species to both the eastern and western Pacific was very low at 8 out of 119 species, with 6 of those 8 being cosmopolitan species. Among *Paracyathus* species, *P. pruinosus* Alcock, 1902 is eurythermic from tropical to warm temperate waters in the Indo-Northwest Pacific, while *P. stearnsii* Verrill, 1869 is eurythermic from tropical to cold temperate waters in the northeastern Pacific (Verrill, 1869; Alcock, 1902; Cairns, 1994). *Paracyathus darwinensis* Cairns, 2004 and *P. montereyensis* Durham, 1947 have also been reported to be endemic species in Australia and the California of northeastern Pacific, respectively (Cairns, 1994, 2004). Based on previous studies, *Paracyathus* is abundant in the Indo-Pacific with its distribution seeming to be isolated between the East and West North

*To whom correspondence should be addressed
Tel: 82-43-531-2892, Fax: 82-43-531-2862
E-mail: buteo2@woosuk.ac.kr, buteo2@gmail.com

eISSN 2234-8190

Pacific or within the local regions.

As an unrecorded species, *Paracyathus rotundatus* Semper, 1872 is newly reported for the first time in Korean waters in this study through a taxonomic study on solitary caryophyllid specimens. Through this study, *Paracyathus* is firstly added to anthozoan fauna of Korea, consequently a total of 7 genera and 8 species in family Caryophylliidae are reported.

MATERIALS AND METHODS

Specimens were collected from the subtidal zone of Dokdo in the East Sea, Geomundo in the South Sea, and Gageodo in the southernmost part of Korea at a depth of 6 m to 28 m from 2019 to 2022. Living corals firmly attached to rock surfaces were photographed with Tough TG-5 (Olympus Digital Solution Corporation, Tokyo, Japan) and A7R IV (Sony Corporation, Tokyo, Japan) digital cameras to record their morphological and ecological features before fixation. Collected specimens were fixed with 99% alcohol (v/v) for further morphological examination and molecular experiments.

For identification, detailed morphological characteristics of corallum, costae, septa, pali, and columella were examined under a stereomicroscope (SteREO Discovery. V8; Carl Zeiss, Jena, Germany). During examinations, all images of corallite were taken using a CMOS sensor microscope digital camera (KCS-2000SS; Korea Lab Tech, Seongnam, Korea). All measurements were taken with an image analyzer (OptiView; Korea Lab Tech) and a ruler.

Molecular experiments were performed to compare genetic distances between corals according to color variation in septa, pali, and columella. Total DNAs were extracted from ethanol preserved specimens using a DNeasy Blood and Tissue Kit (Qiagen, Hilden, Germany) according to the manufacturer's protocol. Partial 16S rRNA sequences were amplified using published primers (LP16SF: 5′-TTGACCGGTATGAATGG TGT-3′ and LP16SR: 5′-TCCCCAGGGTAACTTTTATC-3′) (Le Goff-Vitry et al., 2004). Amplification was carried out on a MiniAmp thermal cycler (Thermo Fisher Scientific Inc., Waltham, MA, USA) using TaKaRa Ex Taq (Takara Bio Inc., Kusatsu, Japan) for 50 μL reactions. PCR conditions were fixed as follows: denaturation at 95°C for 5 min; 35 cycles of denaturation at 95°C for 30 s, annealing at 50–55°C for 30 s, and extension at 72°C; followed by a final extension step at 72°C for 10 min. Analysis of genetic distances and phylogeny were performed using the Molecular Evolutionary Genetics Analysis (MEGA) software version 11 (Tamura et al., 2021).

Specimens were deposited in the National Marine Biodiversity Institute of Korea, Seocheon (MABIK CN000 81231–CN00081234) and Cnidaria Bioresources Bank of Korea, Woosuk University, Jincheon (CBB19CnAnE478, CBB22CnAnE059).

SYSTEMATIC ACCOUNTS

Phylum Cnidaria Hatschek, 1888
Class Anthozoa Ehrenberg, 1834
Subclass Hexacorallia Haeckel, 1896
Order Scleractinia Bourne, 1900
Family Caryophylliidae Dana, 1846

[1*]Genus *Paracyathus* Milne Edwards and Haime, 1848

Cyathina (*Paracyathus*) Milne Edwards and Haime, 1848: 330–331.

Diagnosis. Corallum solitary form, turbinate or trochoid, fixed or free. Septotheca costae. Pali of paliform lobes present, not arranged in crowns, occurring before all septa excluding last cycle, and lobes usually bi- or trilobed. Columella papillose, often indistinguishable from lower paliform lobes.

[2*]*Paracyathus rotundatus* Semper, 1872 (Table 1, Figs. 1, 2)

Paracyathus rotundatus Semper, 1872: 253–254, Pl. 20, fig. 15a, b; Cairns and Zibrowius, 1997: 115–116, fig. 13d–e; Cairns, 1998: 380; 2004: 284.

Paracyathus caeruleus Duncan, 1889: 5, Pl. I, figs. 10, 11; Pillai, 1972: 210.

Paracyathus merguiensis Duncan, 1889: 6, Pl. I, figs. 12–14; Pillai, 1972: 210.

Material examined. Korea: 4 corallums, Jeollanam-do: Sinan-gun, Heuksan-myeon, Gageodo-gil, 34°02′47″N, 125° 07′22″E, 19 Aug 2019, Jeong SC, Lee SJ, Park SH, 25–28 m; 9 corallums, Sinan-gun, Heuksan-myeon, Gageodo-gil, 34°05′ 54″N, 125°05′29″E, 20 Aug 2019, Jeong SC, Lee SJ, Park SH, 15–20 m; 3 corallums, Yeosu-si, Samsan-myeon, Geomun-gil, 34°00′58″N, 127°19′26″E, 28 Aug 2019, Hwang SJ, Jeong SC, Lee SJ, 10 m; 4 corallums, Yeosu-si, Samsan-myeon, Geomun-gil, 34°00′55″N, 127°19′26″E, 23 Oct 2021, Hwang SJ, Jeong SC, Lee KH, Lee SJ, 10–23 m; 1 corallum, Yeosu-si, Samsan-myeon, Geomun-gil, 34°01′05″N, 127°17′ 39″E, 23 Oct 2021, Hwang SJ, Jeong SC, Lee KH, Lee SJ, 10–25 m; 11 corallums, Gyeongsangbuk-do: Ulleung-gun, Ulleung-eup, Dokdoisabu-gil, 37°14′22″N, 131°51′55″E, 2 Jul 2022, Hwang SJ, Jeong SC, Lee KH, Lee SJ, Yu HJ, 6–10 m.

Korean name: [1*]측컵돌산호속(신칭), [2*]둥근측컵돌산호(신칭),

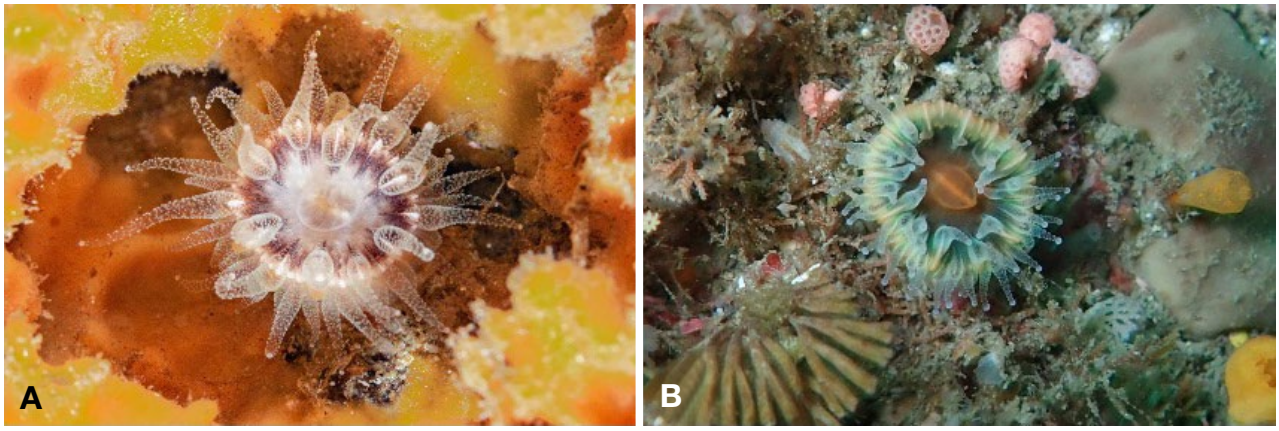

Fig. 1. Living corallums of *Paracyathus rotundatus*. A, Fully relaxed coral surrounded by sponge at subtidal zone of Dokdo; B, Coral attaching on rocky slope at subtidal zone of Geomundo.

All specimens were collected by SCUBA diving.

Description. Azooxanthellate. Corallum somewhat cylindrical with narrow pedicel above broad base, firmly fixed by robust pedicel, calice elliptical, 7.7–12.8 mm in height (base to calicular), 6.0–11.2 mm in height (pedicel to calicular), 7.0–12.5 mm in greater calicular diameter (GCD), 6.0–10.5 mm in lesser calicular diameter (LCD), and ratio of GCD : LCD ranges from 1.11 to 1.50 (Fig. 2A–D). Pedicel 6.0–7.7 mm in diameter with ratio of PD (pedicel diameter) : GCD ranges from 0.57 to 0.87. Costae well developed from calicular margin to base, 0.21–0.43 mm in width, covered with tiny granules, separated by intercostal striae with 0.10–0.23 mm wide. Septa hexamerally arranged up to 5 cycles, but 5th incomplete in all specimens, largest and smallest specimens with 78 and 52 septa, respectively (Fig. 2F). All septa project above thecal wall, but unequally. S1 and S2 distinctly exsert from 1.0–1.7 mm, and exsertions sequentially decrease toward S3, S4, and S5. Upper thecal edges of S4 more or less fused to adjacent S1 or S2. Septal faces have numerous tiny and somewhat spinose granules arranged in transverse rows, larger and blunt toward inner edges. Upper edge of septa curved outward, inner septal edges vertical. Primary septa (S1) largest with 1.9–3.3 mm in width, and 0.3–0.6 mm thick. Secondary septa (S2) slightly smaller than S1, 1.8–2.9 mm in width, and 0.4–0.5 mm thick. Third septa (S3) and fourth septa (S4) 1.6–2.9 mm and 1.3–2.4 mm in width, respectively. Fifth septa (S5) smallest with 1.0–2.4 mm in width. S3 slightly thicker than or almost same as S4 with 0.3–0.5 mm thick, and S5 thinnest with 0.2–0.3 mm thick. Septal formula S1 > S2 > S3 > S4 > S5 in larger specimens over 10 mm of GCD, but S1 ≥ S2 > S3 > S4 > S5 in smaller than 9 mm. Pali well developed except last septal cycle, little thicker than associated septa, divided into multiple lobes, crowded between septa and columella, sometimes indistinguishable from columella (Fig. 2E). Pali (P1) associated with S1 usually 1 or 2 lobes, P2 and P3 divided into 2 and 2–3, respectively, but sometimes more in larger specimens, P4 frequently fuse with P3. Fossa deep. Columella concave, crowded, and composed of 20–30 slender papillose elements resembling lobed or club-shaped stigmas (Fig. 2E). Papillose more numerous in larger specimens.

Color. While alive, tentacles are transparent, with rounded white knobs at their tips and tiny wart-like nematocyst batteries scattered on surface (Fig. 1). Oral parts are more or less transparent white or slightly pale orange. A very light cherry blossom color is found for sides of cups. However, this color is bleached in alcohol (Figs. 1B, 2D). Upper margins of edges of septa are white (Fig. 2A–C). The rest of tops and sides are brown, with blue-green towards the center of cups. Sometimes they are all blue-green except for their top edges. Pali and columella are white or light sky-blue or blue-green. Even after preservation in alcohol, colors of septa, pali, and columella are not bleached.

Ecology and habitat. Corals live in somewhat shaded places on slopes of rocks within 30 m of subtidal waters (Fig. 1). Usually, several corals do not form a group, but live scattered. Occasionally, marine invertebrates such as barnacles and bryozoans adhere to the surface of corallums (Fig. 2D).

Distribution. Indian Ocean: Myanmar, Western Australia (Dampier); Pacific Ocean: South China Sea to Indonesia, Philippines (Lapinig Canal), Korea (Dokdo, Geomundo, Gageodo).

Remarks. *Paracyathus rotundatus* was first described by Semper (1872) based on a single specimen collected at Lapinig, Northern Samar of Philippines. *Paracyathus caeruleus* Duncan, 1889 and *P. merguiensis* Duncan, 1889 were synonymized as this species by Cairns (1998). Our materials agreed

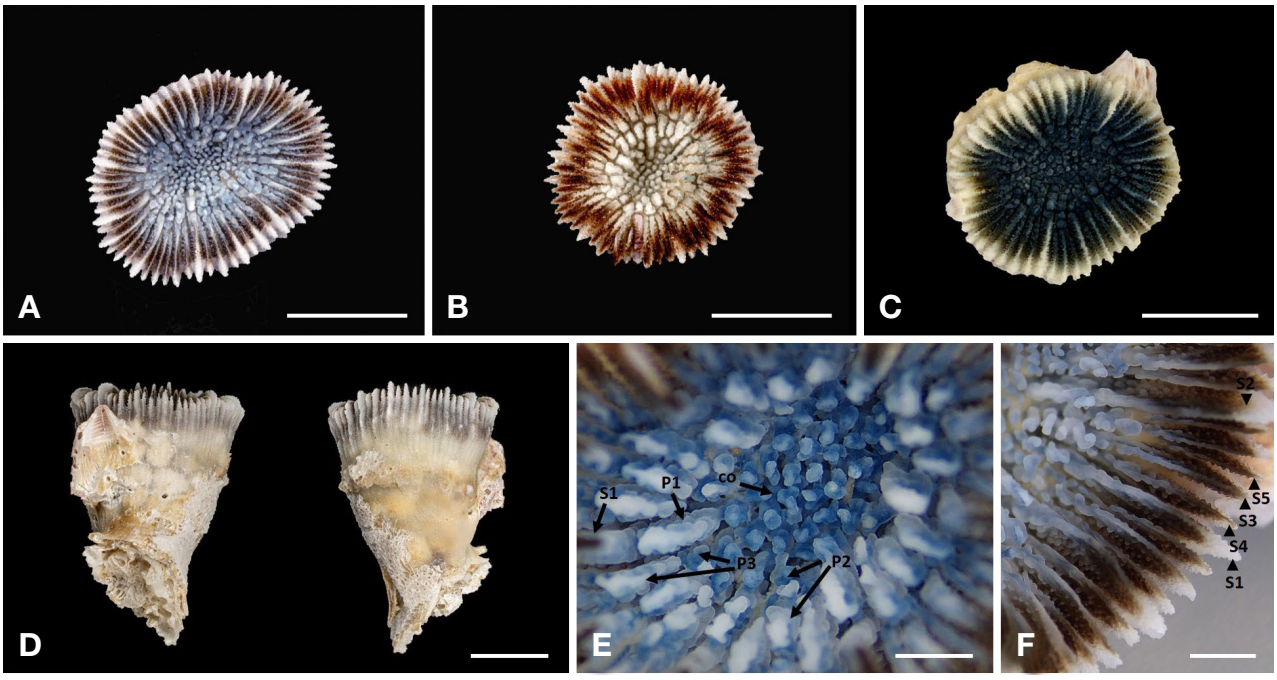

Fig. 2. Stereo microscope images of *Paracyathus rotundatus*. A–C, Calicular views of specimens; D, Lateral views of specimen; E, Concave columella with numerous slender papillose elements resembling lobed or club-shaped stigmas and pali; F, 5 cycles of septa and septal faces with tiny granules arranged in transverse rows. co, columella; P1, pali associated with S1; P2, pali associated with S2; P3, pali associated with S3; S1, primary septa; S2, secondary septa; S3, third septa; S4, fourth septa; S5, fifth septa. Scale bars: A–D = 5 mm, E = 0.5 mm, F = 1 mm.

Table 1. Genetic distances within and between species of the genus *Paracyathus* based on partial 16S rRNA in 269 bp length

Species (GenBank accession No.)	*P. rotundatus*[a] Dokdo, this study	*P. rotundatus*[b] Dokdo, this study	*P. rotundatus*[c] Geomundo, this study	*P. pulchellus* Mediterranean
P. rotundatus (OQ170794)				
P. rotundatus (OQ170795)	0.000			
P. rotundatus (OQ170796)	0.000	0.000		
P. pulchellus (AF265603)	0.113	0.113	0.113	

[a]A specimen with brown septa and sky-blue pali and columella.
[b]A specimen with brown septa and white pali and columella.
[c]A specimen with blackish-blue septa and blue-green pali and columella.

with the original descriptions, in particular the shape and size of corallum, the ratio of GCD : LCD, the broad base, distinct broad costae from calice to base, incomplete 5 cylcles of septa, septal formular, all exsert septa, pali divided into multiple lobes, and a concave columella composed of numerous papillary processes could undoubtedly identify the species.

This species is known to have color variations such as brown, blackish-brown, purple gray, blue, and intense Prussian-blue in septa, pali, and columella. Specimens from Korean waters also have similar color variations. In this study, as a result of comparing partial 16S rRNA sequences with a length of 269 bp according to color variation (GenBank accession No. OQ170794–OQ170796), it was found that there were no sequence differences between a specimen with blackish-blue septa and blue-green pali and columella, a specimen with brown septa and white pali and columella, and a specimen with brown septa and sky-blue pali and columella (Table 1). In addition, through comparing 16S rRNA sequences of *P. pulchellus* (Philippi, 1842) stored in GenBank (accession No. AF265603), a genetic distance between species was 11.3%, confirming that that the color variation was owing to intraspecific variation.

ORCID

Su-Hwan Sim: https://orcid.org/0000-0002-6030-7253
Hyo-Jin Yu: https://orcid.org/0000-0002-4143-1101
Sang-Hoon Park: https://orcid.org/0000-0001-7255-0819
In-Young Cho: https://orcid.org/0000-0002-0979-7971
Won-Gi Min: https://orcid.org/0000-0003-3225-7372
Sung-Jin Hwang: https://orcid.org/0000-0002-1259-6775

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGMENTS

This research was supported by National Marine Biodiversity Institute of Korea (2022M01100). And also, this research was partly supported by A Sustainable Research and Development of Dokdo funded by the Ministry of Oceans and Fisheries (PG52911).

REFERENCES

Alcock A, 1893. On some newly-recorded corals from the Indian Seas. Journal of the Asiatic Society of Bengal (Natural History), 62:138-149.

Alcock A, 1902. Report on the deep-sea Madreporaria of the Siboga-expedition. Siboga Expeditie, 16a:1-52, pls. 1-5. https://doi.org/10.5962/bhl.title.11383

Altuna A, Ríos P, 2014. Scleractinia (Cnidaria: Anthozoa) from INDEMARES 2010-2012 expeditions to the Avilés Canyon System (Bay of Biscay, Spain, northeast Atlantic). Helgoland Marine Research, 68:399-430. https://doi.org/10.1007/s10152-014-0398-z

Cairns SD, 1994. Scleractinia of the temperate North Pacific. Smithsonian Contributions to Zoology, 557:1-150. https://doi.org/10.5479/si.00810282.557.i

Cairns SD, 1998. Azooxanthellate Scleractinia (Cnidaria: Anthozoa) of Western Australia. Records of the Western Australian Museum, 18:361-417.

Cairns SD, 2004. Azooxanthellate Scleractinia (Coelenterata: Anthozoa) of Australia. Records of the Australian Museum, 56:259-329. https://doi.org/10.3853/j.0067-1975.56.2004.1434

Cairns SD, Chapman RE, 2001. Biogeographic affinities of the North Atlantic deep-water Scleractinia. In: Proceedings of the First International Symposium on Deep-Sea Corals, Ecology Action Centre and Nova Scotia Museum, Halifax, pp. 30-57.

Cairns SD, Kitahara MV, 2012. An illustrated key to the genera and subgenera of the recent azooxanthellate Scleractinia (Cnidaria, Anthozoa), with an attached glossary. ZooKeys, 227:1-47. https://doi.org/10.3897/zookeys.227.3612

Cairns SD, Zibrowius H, 1997. Cnidaria Anthozoa: azooxanthellate Scleractinia from the Philippine and Indonesian regions. Mémoires du Muséum National d'Histoire Naturelle, 172:27-243.

Choi E, Song JI, 2015. New records of two genera *Leptoseris* and *Phyllangia* (Anthozoa: Hexacorallia: Scleractinia) from Korea. Animal Systematics, Evolution and Diversity, 31:146-152. https://doi.org/10.5635/ASED.2015.31.3.146

Duncan PM, 1876. Notices of some deep-sea and littoral corals from the Atlantic Ocean, Caribbean, Indian, New-Zealand, Persian Gulf, and Japanese Seas. Proceedings of the Zoological Society of London, 44:428-442. https://doi.org/10.1111/j.1096-3642.1876.tb02582.x

Duncan PM, 1889. On the Madreporaria of the Mergui Archipelago collected for the Trustees of the Indian Museum, Calcutta by Dr. John Anderson, F.R.S., Superintendent of the Museum. Journal of the Linnaean Society, 21:1-25. https://doi.org/10.1111/j.1096-3642.1886.tb00967.x

Hoeksema BW, Cairns S, 2022. World List of Scleractinia. Caryophylliidae Dana, 1846 [Internet]. World Register of Marine Species, Accessed 12 Dec 2022, <https://www.marinespecies.org/aphia.php?p=taxdetails&id=135073>.

Le Goff-Vitry MC, Rogers AD, Baglow D, 2004. A deep-sea slant on the molecular phylogeny of the Scleractinia. Molecular Phylogenetics and Evolution, 30:167-177. https://doi.org/10.1016/S1055-7903(03)00162-3

Lindström G, 1877. Contributions to the actinology of the Atlantic Ocean. Kongliga Svenska Vetenskaps-Akademiens Handlingar, 14:1-26.

Milne Edwards H, Haime J, 1848. Recherches sur les polypiers. Mémoire 2. Monographie des turbinolides. Annales des Sciences Naturelles, Zoologie, Series 3, 9:211-344.

Pillai CSG, 1972. Stony corals of the seas around India. In: Proceedings of the First International Symposium on Corals and Coral Reefs, Marine Biological Association of India, Mandapam Camp, pp. 191-216.

Semper C, 1872. Uber Generationswechsel bei steinkorallen und über das M.-Edwards'sche wachstumgesetz der polypen. Zeitschrift fur Wissenschaftliche Zoologie, 22:235-280.

Singarayan L, Rethnaraj C, 2016. Occurrence of azooxanthellate scleractinian corals off Goa, mid-west coast of India. Marine Biodiversity Records, 9:78. https://doi.org/10.1186/s41200-016-0080-z

Song JI, 1982. A study on the classification of the Korean Anthozoa: 7. Scleractinia (Hexacorallia). The Korean Journal of Zoology, 25:131-148.

Song JI, 1991. A systematic study on the Korean Anthozoa: 12. Order Scleractinia. The Korean Journal of Systematic Zoology, 7:127-150.

Tamura K, Stecher G, Kumar S, 2021. MEGA11: molecular evolutionary genetics analysis version 11. Molecular Biology and

Evolution, 38:3022-3027. https://doi.org/10.1093/molbev/msab120

Verrill AE, 1866. Synopsis of the polyps and corals of the North Pacific exploring expedition, under Commodore C. Ringgold and captain John Rodgers, U.S.N., from 1853 to 1856. Collected by Dr. Wm. Stimpson, naturalist to the expedition. With descriptions of some additional species from the west coast of North America. Part III. Madreporaria. Communications of the Essex Institute, 5:17-50.

Verrill AE, 1869. On new and imperfectly known Echinoderms and Corals. Proceedings of the Boston Society of Natural History, 12:381-396.

Received December 27, 2022
Revised December 29, 2022
Accepted January 16, 2023