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Three new records of Keratosa sponges (Demospongiae: Porifera) from the Andaman and Nicobar Islands, India

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Abstract
Keratose sponges (Keratosa Grant, 1861) of India have not been studied much in detail. The present investigation is part of exploratory sponge taxonomy studies conducted at several localities in the Andaman and Nicobar Islands during 2015–2018. Three keratose sponges distributed among three different families are reported herein for the first time from the Andaman and Nicobar Islands: *Dysidea granulosa* Bergquist, 1965 (Dysideidae Gray, 1867); *Dictyodendrilla cavernosa* (Lendenfeld, 1888) (Dictyodendrillidae Bergquist, 1980), *Phyllospongia papyracea* (Esper, 1806) (Thorectidae Bergquist, 1978). Among these, *D. cavernosa* is a new record to India. Taxonomic descriptions of all the three species are provided and their distribution within the Andaman and Nicobar Islands *vis-à-vis* Indo-Pacific is discussed.

Keywords Dictyoceratida · Dictyodendrillidae · Dysideidae · Marine record · Thorectidae

1 Introduction

Keratose sponges (Keratosa Grant, 1861) have recently been recognized as an important contributor to reefs [1]. These sponges have constituted an informal taxonomic group of non-spicular demospongiae [2] that are characterized by skeletal structures of organic collagenous material, or spongin fibers [1, 3, 4]. However, Keratosa has been genetically and phylogenetically accepted and is currently represented by two orders; viz., Dendroceratida Minchin, 1900 and Dictyoceratida Minchin, 1900 [5, 6].

Keratose sponges of India have not been studied much in detail. Knowledge of taxonomy and diversity of keratose sponges in India mainly stems from the works of Carter [7, 8], Dendy [9, 10], Burton [11], Rao [12], Thomas [13] and Sivaleela [14] in the east coast of India and from Lendenfeld [15], Dendy [16] and Subba Rao and Sastry [17] in the west coast of India. Contributions from the island ecosystems of India include Thomas [18, 19], Prabhakaran [20] and Gopi and Kumar [21] in the Lakshadweep and from Dam Roy et al. [22], Immanuel et al. [23] and Das et al. [24] in the Andaman and Nicobar Islands. More recently, George et al. [25] provided a checklist of marine sponges including keratosa from the peninsular coasts of India. Altogether, a total of 46 keratosa sponges (37 dictyoceratids and nine dendroceratids) distributed among 12 families and 24 genera are reported to be present in India so far.

This report is a part of exploratory sponge taxonomy studies conducted at several localities in the Andaman and Nicobar Islands during 2015–2018. Three keratose sponges distributed among three different families are reported herein

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for the first time from the Andaman and Nicobar Islands: *Dysidea granulosa* Bergquist, 1965 (Dysideidae Gray, 1867); *Dictyodendrilla cavernosa* (Lendenfeld, 1888) (Dictyodendrillidae Bergquist, 1980), *Phyllospongia papyracea* (Esper, 1806) (Thorectidae Bergquist, 1978). Among these, *D. cavernosa* is a new record to India. Taxonomic descriptions of all the three species are provided and their distribution within the Andaman and Nicobar Islands *vis-à-vis* Indo-Pacific according to the marine ecoregions defined by Spalding et al. [26] is discussed.

2 Material and methods

2.1 Keratose sponges reported to be present in India in earlier studies

Scientific literature dealing with records of these sponges from India were critically reviewed from present-day taxonomic, nomenclatural and distribution aspects. All keratose sponges recorded from India were reviewed in consultation with the World Porifera Database [6] and classified into three categories, viz., verified, unverified and inaccurate (Table 1).

2.2 Study area

Andaman and Nicobar Islands (06° 45′–13° 41′ N; 92° 12′–93° 57′ E) (Fig. 1, map indicating the position of the Andaman and Nicobar Islands in the Indian Ocean on top left was prepared using SimpleMappr [27]; Table 2) are the emergent peaks of long ridge that extends from the Arakan-Yoma range of Myanmar to Sumatra of Indonesia in a sub-linear north–south direction [28]. The Andaman Island group and the Nicobar Island group are separated by the Ten Degree Channel, which is about 160 km wide [29]. Marine Protected Areas in these Islands comprise nine National Parks and 96 island sanctuaries [30].

2.3 Sampling

The studied material came from 15 sub-tidal localities. The habitats were coral reef with various substrates, viz., rocky, sandy and muddy bottoms. Depths of the surveyed localities ranged from 4 to 18 m. Sponges were collected using snorkeling and SCUBA and specimens were fixed and preserved in 70% ethanol and brought to the laboratory.

Histological sections were prepared by serially dehydrating sponge fragments in 70% and by 100% ethanol for 1–2 h and immersing in xylene for 24 h. The fragments were later immersed in paraffin-xylene for 24 h and embedded in paraffin wax. Sections were made using a razor blade and followed by immersion in xylene for dewaxing. Permanent slides were prepared by mounting the sections and spicules using DPX [31, 32]. The sections were then observed and photographed using a stereo-zoom microscope (Make: Leica; Model: M205A) and a compound microscope (Make: Omax; Model: XM82ESC02).

The specimens were identified using the classification scheme of World Porifera Database and *Systema Porifera* [6, 33]. Original descriptions were used for comparison and establishing the identity of the reported species. The specimens were registered and deposited at the National Zoological Collections at Zoological Survey of India, Andaman Nicobar Regional Centre (ZSI/ANRC), Port Blair.

3 Results

3.1 Systematics

Order Dictyoceratida Minchin, 1900

Definition. Dictyoderatid sponges possess a skeleton made up of spongin fibers, which makes up a significant proportion of the body volume. In a few cases, the sponge may include foreign particles [34].

Table 1 An overview of the keratose sponges (n = 46) reported to be present in India

Species	References and locality data in India	Remarks
Subclass Keratosa Grant, 1861		
Order Dictyoceratida Minchin, 1900		
Family Irciniidae Gray, 1867		
Genus *Ircinia* Nardo, 1833 **(9 species)**		
Ircinia aruensis Hentschel, 1912	Burton [11]; Krusadai Island [as *Hircinia aruensis* Hentschel, 1912]	Type locality is Arafura Sea; distribution in India is unverified
Ircinia arundinacea (Carter, 1880)	Carter [7]; Gulf of Mannar [as *Hircinia arundinacea* Carter, 1880]	Type locality is South India and Sri Lanka; distribution in India is verified
Ircinia cactiformis Rao, 1941	Rao [12]; Pamban [as *Hircinia ccactiformes*]	Type locality is South India and Sri Lanka; distribution in India is verified
Ircinia campana (Lamarck, 1814)	Prabhakaran [20]; Lakshadweep	Type locality is Caribbean Sea; distribution in India is inaccurate
Ircinia fusca (Carter, 1880)	Carter [7] [as *Hircinia fusca* Carter, 1880] Burton [11]; Krusadai Island [as *Hircinia fusca* Carter, 1880] Carter [8]; Gulf of Mannar Thomas [13]; Gulf of Mannar and Palk Bay	Type locality is South India and Sri Lanka; distribution in India is verified
Ircinia ramodigitata Burton, 1934	Rao [12]; Pamban [as *Hircinia ramodigitata*]	Type locality is Great Barrier reef; distribution in India is unverified
Ircinia ramosa (Keller, 1889)	Burton [11]; Krusadai Island [as *Hircinia ramosa* Keller, 1889] Thomas [13]; Gulf of Mannar	Type locality is Southern Red Sea; distribution in India unverified
Ircinia strobilina (Lamarck, 1816)	Dam Roy et al. [22]; Avis Island Immanuel et al. [23]; Andaman and Nicobar Islands	Distribution in India is inaccurate
Ircinia vallata (Dendy, 1887)	Dendy [9]; Rameswaram [as *Hircinia vallata* Dendy, 1887] George et al. [25]	Type locality is Eastern India; distribution in India is verified
Genus *Sarcotragus* Schmidt, 1862 **(1 species)**		
Sarcotragus tuberculatus (Poléjaeff, 1884)	Thomas [13]; Gulf of Mannar [as *Ircinia tuberculata* (Polejaeff, 1884)]	Type locality is Cape Howe; distribution in India unverified
Family Thorectidae Berquist, 1978		
Genus *Fascaplysinopsis* Bergquist, 1980 **(1 species)**		
Fascaplysinopsis reticulata (Hentschel, 1912)	Burton [11]; Krusadai Island [as *Aplysinopsis reticulata* Hentschel, 1912] Rao [12]; Pamban [as *Aplysinopsis reticulata* Hentschel, 1912] George et al. [25]	Type locality is contained in Arafura Sea, reported in Indian EEZ, distribution in India is verified
Genus *Cacospongia* Schmidt, 1862 **(1 species)**		
Cacospongia mollior Schmidt, 1862	Thomas [13]; Gulf of Mannar	Lectotype from Adriatic Sea, distribution in India is inaccurate
Genus *Scalarispongia* Cook & Bergquist, 2000 **(1 species)**		
Scalarispongia scalaris (Schmidt, 1862)	Thomas [13]; Gulf of Mannar [as *Cacospongia scalaris* Schmidt, 1862]	Type locality is Adriatic Sea; distribution in India is inaccurate

Table 1 (continued)

Species	References and locality data in India	Remarks
Genus *Fasciospongia* Burton, 1934 **(2 species)**		
Fasciospongia anomala (Dendy, 1905)	Thomas [13]; Gulf of Mannar Sivaleela [14]; Gulf of Mannar George et al. [25]	Type locality is South India and Sri Lanka; distribution in India is verified
Fasciospongia cavernosa (Schmidt, 1862)	Burton [11]; Krusadai Island Thomas [13]; Gulf of Mannar Thomas [19]; Lakshadweep Prabhakaran [20]; Minicoy Sivaleela [14]; Gulf of Mannar	Type locality is Adriatic Sea; distribution in India is inaccurate
Genus *Hyrtios* Duch. & Mich.1864 **(2 species)**		
Hyrtios erectus (Keller, 1889)	Burton [11]; Krusadai Island [as *Duriella nigra* Row, 1911) Thomas [13]; Gulf of Mannar and Palk Bay [as *Heteronema erecta* Keller] Thomas [19]; Kalpeni Dam Roy et al. [22]; Ross Island Gopi and Kumar [21]; Lakshadweep Immanuel et al. [23]; Andaman and Nicobar Islands George et al. [25]	Type locality is Southern Red sea and Gulf of Aden; reported in South India and Sri Lanka; distribution in India is verified
Hyrtios reticulatus (Thiele, 1899)	George et al. [25]	Type locality in Sulawesi, distribution in India is verified
Genus *Luffariella* Thiele, 1899 **(1 species)**		
Luffariella herdmani (Dendy, 1905)	Dendy [10] George et al. [25]	Type locality is South India and Sri Lanka, distribution in India is verified
Genus *Smenospongia* Wiedenmayer,1977 **(1 species)**		
Smenospongia aurea (Hyatt, 1875)	Burton [11]; Krusadai Island [as *Luffariospongia clathrata*] Rao [12]; Pamban [as *Luffariospongia clathrata*] Thomas [13]; Gulf of Mannar and Palk Bay Thomas [18]; Minicoy Island Thomas [19]; Lakshadweep Prabhakaran [20]; Lakshadweep Gopi and Kumar [21]; Lakshadweep [as *Hyattella cribriformis* (Hyatt, 1875)]	Type locality contained in Greater Antilles and Bahamian; distribution in India is inaccurate
Genus *Lendenfeldia* Bergquist, 1980 **(2 species)**		
Lendenfeldia dendyi (Lendenfeld, 1889)	Thomas [18]; Minicoy Island [as *Phyllospongia dendyi* Lendenfeld, 1889] Thomas [19]; Minicoy Island	Distribution in India unverified
Lendenfeldia foliacea (Ridley, 1884)	George et al. [25]	Type locality is Northern great Barrier reef; distribution in India is verified

Table 1 (continued)

Species	References and locality data in India	Remarks
Genus *Phyllospongia* Ehlers, 1870 **(2 species)**		
Phyllospongia foliascens (Pallas, 1766)	Thomas [18]; Minicoy Island [as *Phyllospongia foliascens* (Pallas, 1766)] Thomas [19]; Minicoy Island Dam Roy et al. [22]; Avis Island Immanuel et al. [23]; Andaman and Nicobar Islands [as *Carteriospongia foliascens* (Pallas, 1766)]	Type locality in Chagos; distribution in India verified
Phyllospongia papyracea (Esper, 1794)	Rao [12]; Pamban	Type locality is Eastern India; distribution in India is verified
Family SPONGIIDAE Gray, 1867		
Genus *Hyattella* Lendenfeld, 1888 **(4 species)**		
Hyattella intestinalis (Lamarck, 1813)	Carter [8]; Gulf of Mannar [as *Hircinia clathrata* Carter, 1881] Dendy [9]; Rameswaram [as *Hircinia clathrata* Carter, 1881] Thomas [13]; Gulf of Mannar Sivaleela [14]; Gulf of Mannar Dendy [16]; Beyt Island [as *Hippospongia clathrata* (Carter, 1881)] Subba Rao and Sastry [17]; Gulf of Kutch George et al. [25]	Type locality is East African coral coast; distribution in India is verified
Hyattella tubaria Lendenfeld, 1889	Lendenfeld [15]; Mumbai George et al. [25]	Type locality in Gulf of Aden, distribution in India is verified
Hyattella sinuosa (Pallas, 1766)	George et al. [25]	Type locality in Mascarene Islands; distribution in India is verified
Hyattella cavernosa (Pallas, 1766)	George et al. [25]	Type locality in Northeastern Brazil; distribution in India Inaccurate
Genus *Spongia* Linnaeus, 1759 **(4 species)**		
Spongia (Spongia) hispida Lamarck, 1814	Thomas [13]; Gulf of Mannar [as *Spongia hispida* Lamarck, 1814] Sivaleela [14]; Gulf of Mannar	Type locality is East Caroline islands; distribution in India is verified
Spongia (Spongia) ceylonensis (Dendy, 1905)	Burton [11]; Krusadai Island Thomas [13]; Gulf of Mannar and Palk Bay Thomas [18]; Minicoy Island [as *Spongia officinalis var. ceylonensis* (Dendy)] Thomas [19]; Minicoy Island George et al. [25]	Type locality is South India and Sri Lanka; distribution in India is verified
Spongia (Spongia) raoi Van Soest & Hooper, 2020	Rao [12] [as *Spongia (Spongia) fenestrata* Rao, 1941]; Pamban	Type locality is South India and Sri Lanka; distribution in India is verified
Spongia (Spongia) officinalis Linnaeus, 1759	Prabhakaran [20]; Lakshadweep Gopi and Kumar [21]; Lakshadweep	Type locality is Mediterranean; distribution in India is inaccurate

Table 1 (continued)

Species	References and locality data in India	Remarks
Family DYSIDEIDAE Gray, 1867		
Genus *Dysidea* Johnston, 1842 **(5 species)**		
Dysidea cinerea Keller, 1889	Dendy [16]; Beyt Island [as *Spongelia cinerea* (Keller, 1889)] Subba Rao and Sastry [17]; Gulf of Kutch	Type locality is southern red sea; distribution in India is verified
Dysidea tupha (Martens, 1824)	Dendy [16]; Dwarka [as *Spongelia elegans* Nardo, 1847]	Type locality is Adriatic Sea; distribution in India is inaccurate
Dysidea fragilis (Montagu, 1818)	Burton [11]; Krusadai Island Rao [12]; Pamban Sivaleela [14]; Gulf of Mannar Thomas [18]; Minicoy Island Thomas [19]; Minicoy Island Prabhakaran [20]; Minicoy Island Gopi and Kumar [21]; Minicoy Island	Type locality is Celtic Seas; distribution in India is inaccurate
Dysidea avara (Schmidt, 1862)	Dendy [16]; Beyt Island [as *Spongelia fragilis var. ramosa* Schulze, 1879] Subba Rao and Sastry [17]; Gulf of Kutch Dam Roy et al. [22]; Havelock Island Immanuel et al. [23]; Andaman and Nicobar Islands	Type locality is Adriatic Sea; distribution in India is inaccurate
Dysidea granulosa Berquist, 1965	Gopi and Kumar [21]; Lakshadweep George et al. [25]	Type locality is West Caroline Islands; distribution in India unverified
Genus *Lamellodysidea* Cook & Bergquist, 2002 **(1 species)**		
Lamellodysidea herbacea (Keller, 1889)	Thomas [13]; Palk Bay Sivaleela [14]; Gulf of Mannar Thomas [18]; Minicoy Island Thomas [19]; Lakshadweep Gopi and Kumar [21]; Lakshadweep Dam Roy et al. [22]; Smith Island Immanuel et al. [23]; Andaman and Nicobar Islands	Type locality in Southern Red sea; distribution in India verified
Order DENDROCERATIDA Minchin, 1900		
Family DICTYODENDRILLIDAE Bergquist, 1980		
Genus *Spongionella* Bowerbank, 1862 **(3 species)**		
Spongionella nigra Dendy, 1889	Burton [11]; Krusadai Island Thomas [13]; Gulf of Mannar George et al. [25]	Type locality is South India and Sri Lanka; distribution in India is verified
Spongionella tubulosa Burton, 1937	Burton [11]; Krusadai Island Thomas [13]; Gulf of Mannar	Type locality is South India and Sri Lanka; distribution in India is verified
Spongionella retiara (Dendy, 1916)	Dendy [16]; Gujarat [as *Megalopastus retiara* Dendy, 1916] Subba Rao and Sastry [17]; Gulf of Kutch	Type locality is Western India; distribution in India is verified

Table 1 (continued)

Species	References and locality data in India	Remarks
Family DARWINELLIDAE Merekowsky, 1879		
Genus *Darwinella* Muller, 1865 **(2 species)**		
Darwinella australiensis Carter, 1885	Dendy [16]; Kiu Subba Rao and Sastry [17]; Gulf of Kutch	Type locality is Bassian; distribution in India is verified
Darwinella muelleri (Schultz, 1865)	Thomas [13]; Gulf of Mannar	Type locality located in Southern Brazil; distribution in India is inaccurate
Genus *Dendrilla* Lendenfeld, 1883 **(2 species)**		
Dendrilla cactos (Selenka, 1867)	Thomas [13]; Gulf of Mannar and Palk Bay Thomas [19]; Lakshadweep	Type locality is Bassian; distribution in India is unverified
Dendrilla membranosa (Pallas, 1766)	Burton [11]; Krusadai Island	Type locality is the Indian Ocean; distribution in India unverified
Genus *Aplysilla* Schulze, 1878 **(1 species)**		
Aplysilla rosea (Barrois, 1876)	Dam Roy et al. [22]; Neil Island Immanuel et al. [23]; Andaman and Nicobar Islands	Type locality is the North Sea; distribution in India is inaccurate
Genus *Chelonaplysilla* de Laubenfels, 1948 **(1 species)**		
Chelonaplysilla delicata Pulitzer-Finali & Pronzato, 1999	Das et al. [24]; South Andaman, Andaman and Nicobar Islands	Type locality is Bismarck Sea; distribution in India verified

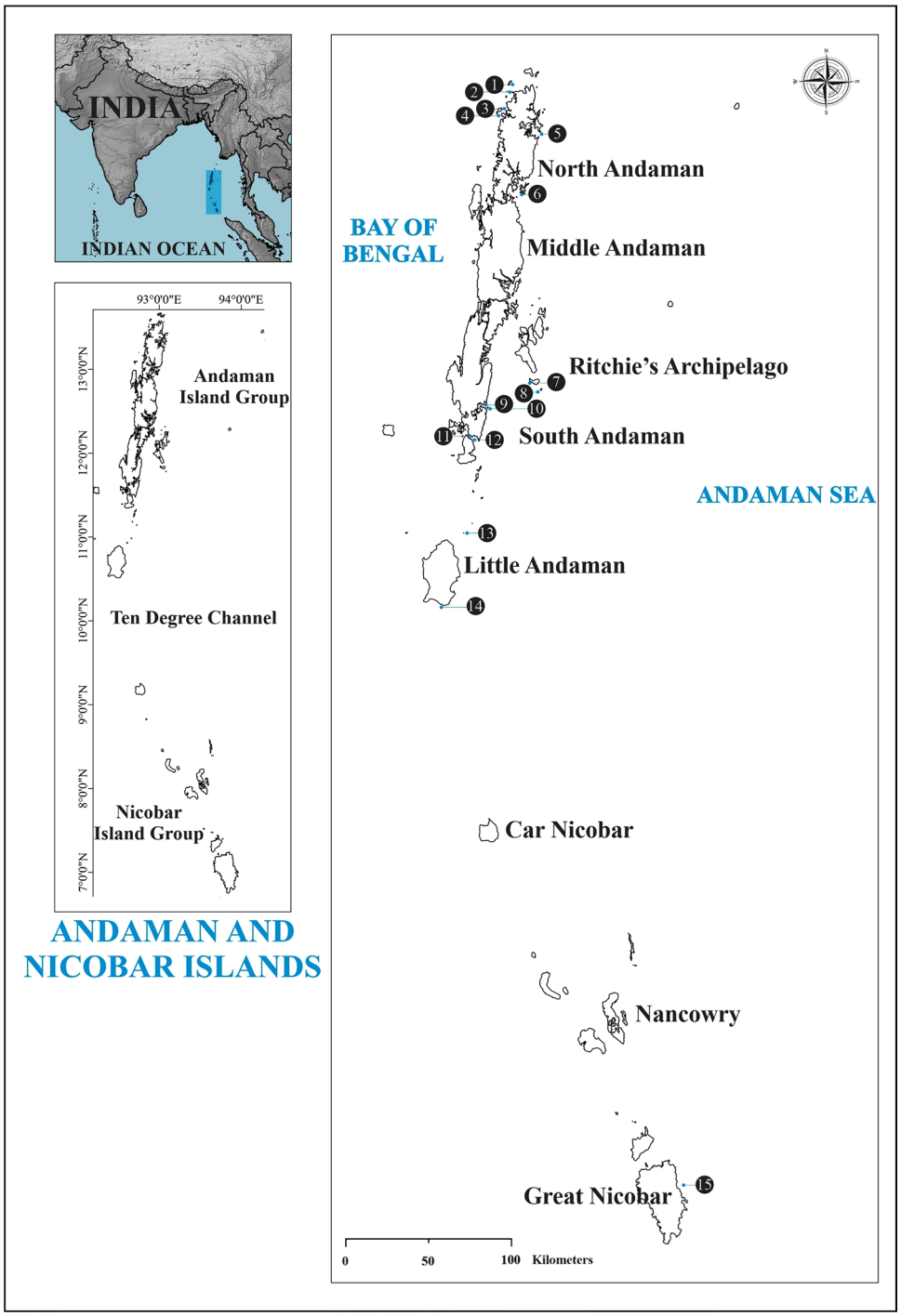

Fig. 1 Map of the Andaman and Nicobar Islands depicting survey localities (n = 15) where species occurrences of keratose sponges were recorded. See Table 2 for names and geographic coordinates

Family Dysideidae Gray, 1867

Definition. Dysideids are uniquely characterized by the presence of eurypylous choanocyte chambers. They also have concentrically laminated and pithed skeletal fibers (to varying degrees), cored fibers and some species have a sand-armoured surface [34].

Genus *Dysidea* Johnston, 1842

Definition. Sponges with marked conulose surface in which fibers are filled with detritus [34].

Table 2 Geographic coordinates of the survey localities (n = 15) where sponge species occurrences were recorded

No.	Survey localities	GPS coordinates		Depth (m)	Sponge species occurrences		
		Latitude (N)	Longitude (E)				
Andaman Island Group					*Dysidea granulosa*	*Dictyodendrilla cavernosa*	*Phyllospongia papyracea*
North Andaman (5 locations)							
1	West Island	13° 34.491′	92° 53.452′	18	•		
2	Thornhill Island	13° 31.820′	92° 54.305′	13	•		
3	Paget Island	13° 26.608′	92° 50.738′	10	•		
4	Point Island	13° 24.395′	92° 49.159′	9	•		
5	Ross Island	13° 17.907′	93° 04.190′	13	•		
Middle Andaman (1 location)							
6	Roper Point, Sound Island	12° 56.469′	92° 57.660′	5	•		
Ritchie's Archipelago (2 locations)							
7	Natural Bridge	11° 49.507′	93° 00.394′	12	•		
8	Sir Hugh Ross Island	11° 47.339′	93°04.796′	13	•		
	Sir Hugh Ross Island (site II)	11° 46.975′	93° 04.566′	13		•	
South Andaman (4 locations)							
9	North Bay	11° 43.006′	92° 45.465′	5	•		
10	Ross Island	11° 40.483′	92° 45.883′	4	•		
11	Rifleman Island	11° 38.765′	92° 35.837′	7	•		
12	Rutland Island	11° 29.030′	92° 40.313′	10	•		
Little Andaman (2 locations)							
13	South Brother Island	10° 56.343′	92° 36.915′	7			•
14	Light House	10° 30.615′	92° 29.143′	10	•		
Nicobar Island Group							
Great Nicobar (1 location)							
15	Pigeon Island	07° 04.669′	93° 54.249′	6	•		

The locations are arranged from north to south (see Fig. 1)

The black circle denotes presence of the species

3.1.1 *Dysidea granulosa* Bergquist, 1965

Synonymy: *Dysidea granulosa* in Bergquist (1965: 144, Fig. 9).

Material examined: 4 specimens, ZSI/ANRC–23598, August 20, 2016, Point Island, Coll. Sudhanshu Dixit; 2 specimens, ZSI/ANRC–23601, December 26, 2017, Pigeon Island, Coll. M. P. Goutham Bharathi; 2 specimens, ZSI/ANRC–23607, February 24, 2018, Ross Island, Coll. M.P. Goutham Bharathi; 2 specimens, ZSI/ANRC–23612, November 18, 2015, Light House, Coll. Sudhanshu Dixit; 4 specimens, ZSI/ANRC–23616, June 23, 2016, Ross Island, Coll. Preeti Pereira; 3 specimens, ZSI/ANRC–23622, August 5, 2016, North Bay, Coll. Sudhanshu Dixit; 2 specimens, ZSI/ANRC–23625, October 5, 2016, Sir Hugh Ross Island, Coll. Sudhanshu Dixit; 4 specimens, ZSI/ANRC–23627, February 22, 2016, Natural Bridge, Coll. Sudhanshu Dixit; 3 specimens, ZSI/ANRC–23630, September 22, 2016, Rifleman Island, Coll. Tamal Mondal; 2 specimens, ZSI/ANRC–23632, August 22, 2016, Paget Island, Coll. Preeti Pereira; 1 specimen, ZSI/ANRC–23633, September 9, 2017, West Island, Coll. Preeti Pereira; 1 specimen, ZSI/ANRC–23635, September 15, 2017, Rutland Island, Coll. Seepana Rajendra; 1 specimen, ZSI/ANRC–23640, September 10, 2017, Thornhill Island, Coll. Seepana Rajendra; 1 specimen, ZSI/ANRC–23642, September 11, 2018, Roper Point, Coll. M.P. Goutham Bharathi.

Description: Slender finger-like branches arising from narrow base, in some cases even grows as a cushion. Surface covered with minute conules, distance between the conules ca. 1 mm. Oscules scattered over the branches in no apparent pattern. Colour when alive dull gray or white with tinges of purple (Fig. 2A). On preservation, colour

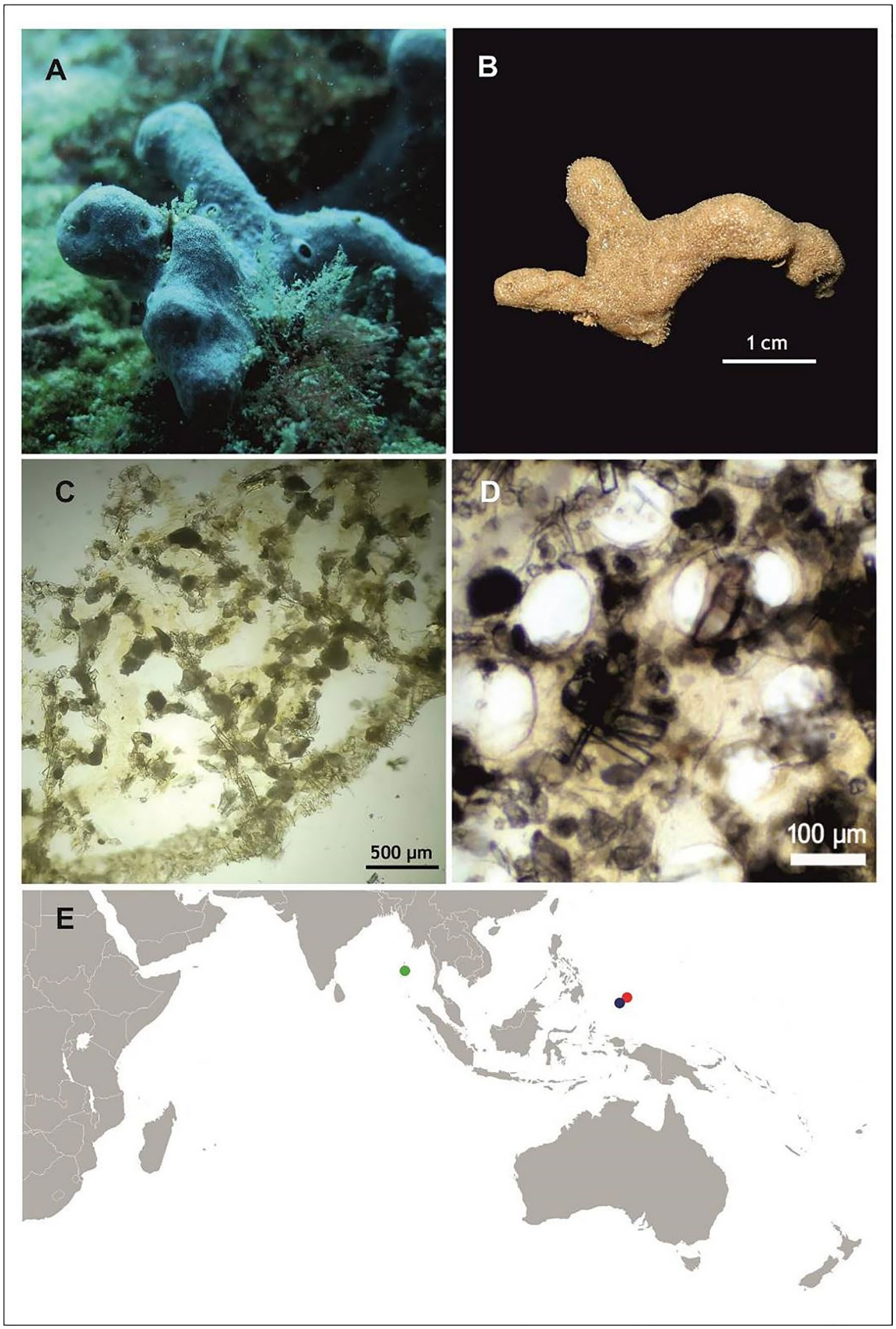

Fig. 2 *Dysidea granulosa* Bergquist, 1965: **A** In situ, **B** Preserved specimen, **C** Tangential section, **D** Tangential section, close-up. **E** Distribution in the Indo-Pacific: blue closed circle—type locality, red closed circle—subsequent records, green closed circle—present study

lightens to dull white or beige (Fig. 2B); preservative is stained a faint purple. Detritus and foreign particles visible, embedded within the body of the sponge and on breaking a fragment of the sponge.

Skeleton: Made up of spongin fibers and foreign bodies (sand particles) (Fig. 2C); both primary and secondary fibers heavily cored with sand particles, indistinguishable from each other. Fibers arranged in a slightly irregular pattern, forming circular or oval meshes measuring 70–300 µm (Fig. 2D).

Distribution: The present study constitutes the first record of *D. granulosa* for the Andaman and Nicobar Islands (Fig. 2E). The type locality of this species is Palau, Micronesia, West Caroline Islands [35]. The species has been reported earlier from Lakshadweep [25], though without species description.

Remarks: Although species of *Dysidea* are morphologically difficult to distinguish [35], *D. granulosa* can be characterized by its growth form and regular surface conules. The species described herein bears a close similarity to the type material in the morphology (growth form and irregular surface conules) and the structure of spongin fibres with irregular meshes and indistinguishable, heavily cored primary and secondary fibres. *Dysidea granulosa* is found to be widely distributed in the Andaman and Nicobar Islands (Table 2) and often observed to grow over bivalves as epibionts.

Family Dictyodendrillidae Bergquist, 1980

Definition. Dictyodendrillid sponges are characterized by their reticulate skeleton, with regular to irregular meshes with strongly laminated fibers and a pronounced pith region [36].

Genus *Dictyodendrilla* Bergquist, 1980

Definition. Sponges with strongly conulose surface, with anastomosing fibres and thick pith [37].

3.1.2 *Dictyodendrilla cavernosa* (Lendenfeld, 1888)

Synonymy: *Dendrilla cavernosa* in Lendenfeld (1888: 29–30).

Material examined: 1 specimen, ZSI/ANRC – 23597, March 23, 2018, Sir Hugh Ross Island, Coll. Preeti Pereira.

Description: Grows upright, digitate, branching at the base (Fig. 3A). Branches cylindrical or tubular (hollow), 6–7 cm high and 3 cm wide. Walls thin, measuring 1–3 mm. Surface conulose with thick, sharp conules, 2–4 mm high; distance between the conules 2–3 mm. Oscules scattered on the surface, usually at the apices, with many pseudoscula. Colour when alive is dull yellow or olive green and turns dull brownish on preservation (Fig. 3B).

Skeleton: Comprised of thickened spongin fibers that project from the surface giving rise to the conules. Fibers thick, 1000–2000 µm, frequently anastomosing and thickest at the base (Fig. 3C). Transverse section of a fiber shows that the pith thickness is almost half the thickness of the fiber (Fig. 3D). Barnacles were found attached to the skeletal fibers within the sponge (Fig. 3E).

Distribution: This constitutes the first record of *D. cavernosa* for India from the Andaman and Nicobar Islands. Further, it also constitutes a new familial record for Dictyodendrillidae from the Islands. The type species was described from Port Jackson, SE Australia, Manning-Hawkesbury in the East Central Australian Shelf (Temperate Australasia) and the only other record was from Port Philips head, South Australia [38]. This is the only second record of *D. cavernosa* in the Indo-Pacific since its original description from Australia, highlighting a significant extension of its distribution range to the western Indo-Pacific realm (Fig. 3F).

Remarks: *Dictyodendrilla cavernosa* is characterized by the distinct, highly conulose surface, erect branching growth form and the pith thickness. Material examined from the Andaman and Nicobar Islands bear close resemblances to the specimens described by Lendenfeld [38] in habit and internal structure: the upright, digitate growth form, surface covered in sharp conules and internally hollow sponge.

Our material was found to be inhabited by a large number of barnacles (Fig. 3E). Barnacles are observed to be camouflaged, probably obtaining food through the canal system of the sponge. Recently, Hosie et al. [39] studied the diversity of dictyoceratid-inhabiting barnacles and highlighted the importance of extensive sampling from different geographical locations. Preliminary observations of *D. cavernosa* as a host sponge for the associated barnacles from the present study might help improve our understanding of sponge-barnacle symbiosis.

Family Thorectidae Bergquist, 1978

Definition. The family encompasses sponges with a wide variety of growth forms from encrusting to massive, upright and foliose or folio-digitate, in which the spongin fibers making up the finely laminated anastomosing

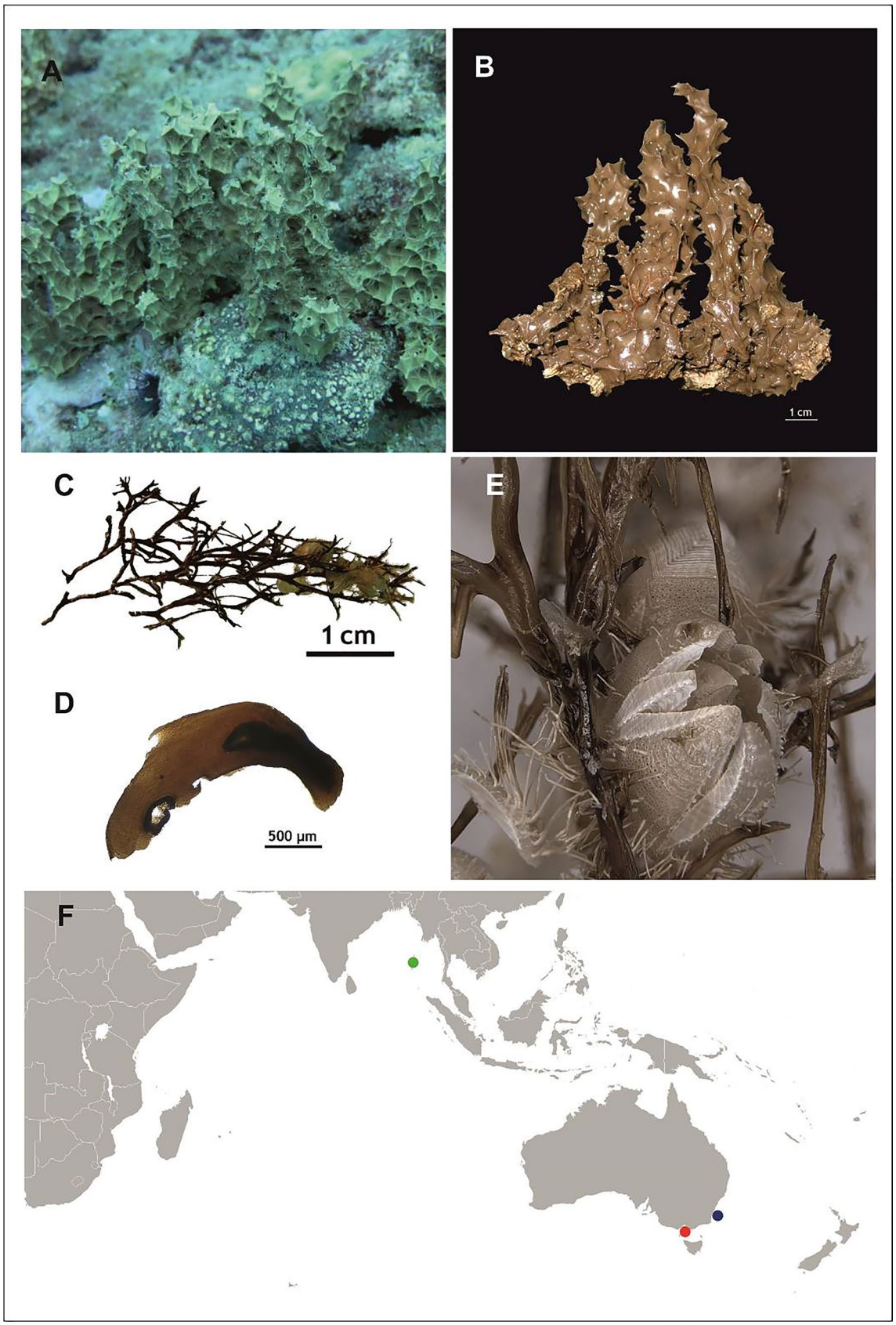

Fig. 3 *Dictyodendrilla cavernosa* (Lendenfeld, 1888): **A** In situ, **B** Preserved specimen, **C** Skeletal fibers, **D** Transverse section of the fibre showing pith, **E** Barnacles encrusting skeletal fibers, **F** Distribution in the Indo-Pacific: blue closed circle—type locality, red closed circle—subsequent record, green closed circle—present study

skeleton containing a differentiated pith. The pith is not easily distinguished from the spongin fibers. These sponges lack spicules and their surface is armoured and forms ridges and troughs [34].

Genus *Phyllospongia* Ehlers, 1870

Definition. Foliose or lamellate sponges with primary and secondary fibres. Primary fibres sometimes armoured with debris, secondary fibres unarmoured [34].

3.1.3 *Phyllospongia papyracea* (Esper, 1806)

Synonymy: *Spongionella holdsworthi* in Bowerbank (1873: 25–32, pls. V–VII), Dendy (1905: 217–218 Pl. XIV, Fig. 6), Bergquist et al. 1988 (304–305, Figs. 13–17) and Bergquist (1995, 9).

Material examined: 1 specimen, ZSI/ANRC–23597, October 10, 2018, South Brother Island, Coll. M.P. Goutham Bharathi.

Description: Cup-like with thin walls, 1–2 mm, with a very slender stalk, 1–2 cm in length. Surface smooth and lacks any grooves or ridges. Colour when alive beige with purple areas and it is retained on preservation (Fig. 4A).

Skeleton: Comprised entirely of anastomosing spongin fibers (Fig. 4B). Primary fibers thick, uncored, interconnected at right angles. Secondary fibers run parallel to the surface; much thinner than the primary fibers.

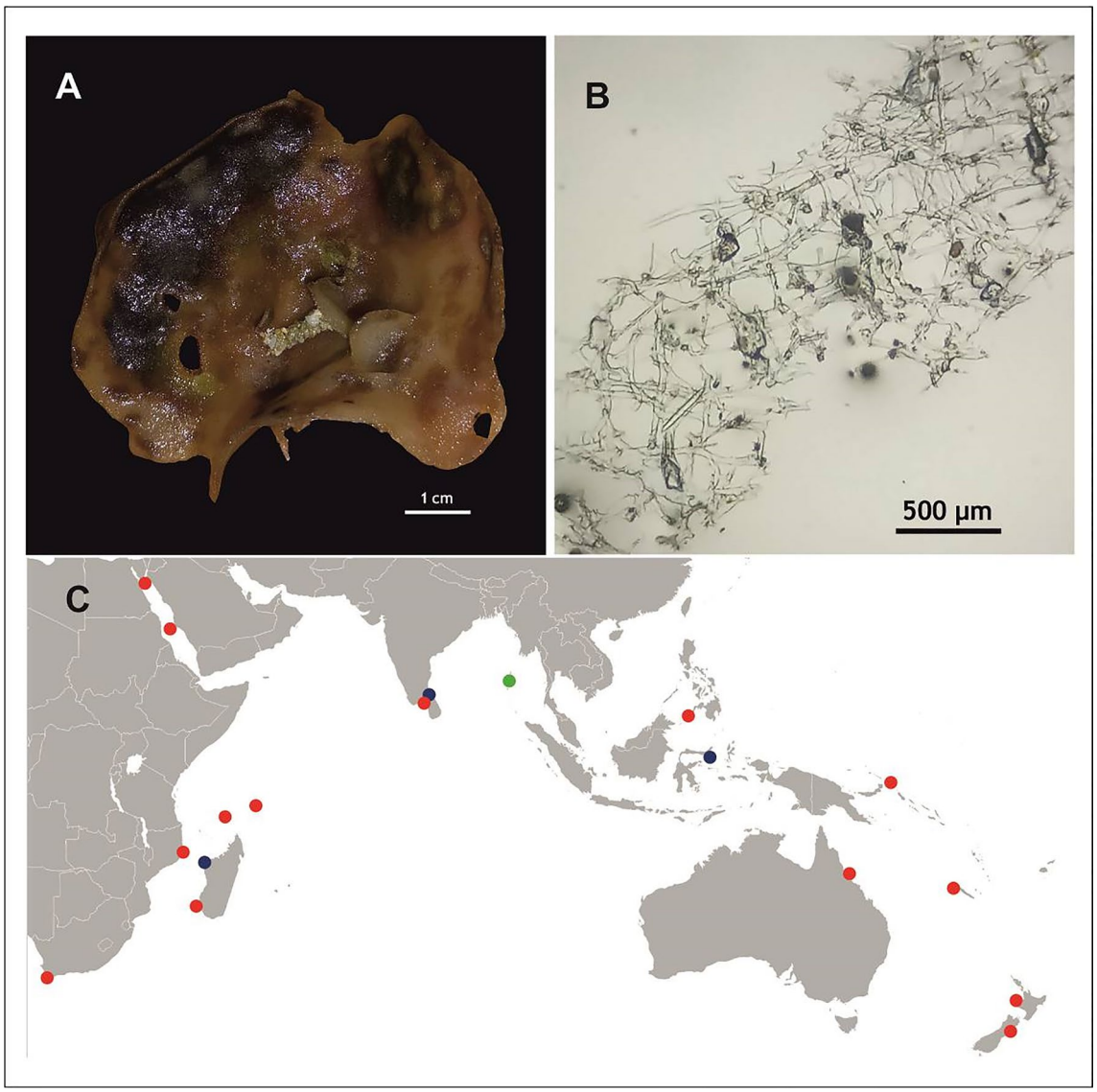

Fig. 4 *Phyllospongia papyracea* (Esper, 1806): **A** Preserved specimen, **B** Tangential section, **C** Distribution in the Indo-Pacific: blue closed circle—type locality, red closed circle—subsequent records, green closed circle—present study

Distribution: *Phyllospongia papyracea* is reported for the first time from the Andaman and Nicobar Islands. The species has previously been reported from Pamban [12] and is common throughout the Indo-Pacific (Fig. 4C). Originally described from the Great Pearl Bank off Arippu, Sri Lanka [40], *P. papyracea* is distributed in Madagascar [41], Gulf of Mannar [10] and Sri Lanka and South India [2].

Phyllospongia papyracea has a widespread distribution ranging from temperate Southern Africa to the temperate Australasia. It has been reported from Cape of Good Hope, Agulhas Bank [41], in the Agulhas Province, New Zealand [15], in Temperate Australasia and Easter Island [42] in the Eastern Indo-Pacific realm. Subsequent records from Central Indo-Pacific include Indonesia, Sulawesi Sea [43], Zamboanga, Palawan/North Borneo [44], Tetel Island in the Western Coral Triangle, Solomon Archipelago [45] in the Eastern Coral Triangle, Reef Dolman, New Caledonia [46] in the Tropical SW Pacific, John Brewer Reef, Great Barrier Reef [2] and Central and Southern Great Barrier Reef [47] in the NE Australian Shelf.

Other records of *P. papyracea* are from Mozambique Island, East African Coral Coast [48], Abu Latt Island, Southern Red Sea [49], Red Sea and Gulf of Aden Province, Aldabra Island, Seychelles [50] in the Western Indian Ocean, Tulear, Grand Récif, Western and Northern Madagascar [51] in the Western Indian Ocean, Hurgada, Northern and Central Red Sea [52] in the Western Indo-Pacific realm.

Remarks: The genus *Phyllospongia* is represented by two species in the Andaman and Nicobar Islands viz., *P. folisascens* and *P. papyracea*. *Phyllospongia papyracea* is morphologically similar to *Phyllospongia foliascens,* which is abundant in the Andaman and Nicobar Islands [53]. The differentiating morphological characters between these two similar species are the smooth surface and the uncored or lightly cored fibers in *P. papyracea* as opposed to the strongly verrucose surface and the strongly cored fibers of *P. foliascens*. The material examined from the Andaman and Nicobar Islands were assigned to *P. papyracea* on account of the thin and lamellate body appearing like a stalked fan. The skeleton is comprised of uncored primary and secondary fibres, typical of the genus *Phyllospongia* [2].

4 Discussion

Among the 46 keratose sponges reported to be present in India, distribution of eight species in India is unverified while the distribution of a further 13 species is inaccurate (Table 1). Several research works cited in Table 1 are old and require extensive taxonomic revisions and these species are in critical need of description and characterization.

In the present study, three keratose sponges are reported for the first time from the Andaman and Nicobar Islands: *Dysidea granulosa, Dictyodendrilla cavernosa* and *Phyllospongia papyracea*. Among these, *D. granulosa* is found to be commonly distributed in the Islands while *D. cavernosa* and *P. papyracea* are found to be rare (known from single specimens) and recorded only from Sir Hugh Ross Island and South Brother Island, respectively (Table 2). Future works on keratose sponges must expand the geographic scope of sampling for authenticating the distribution ranges of these intriguing taxa in the Indo–Pacific.

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Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication All authors agree with the publication of this article.

Competing interests The authors report there are no competing interests to declare.

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References

1. Luo C, Reitner J. First report of fossil "keratose" demosponges in Phanerozoic carbonates: preservation and 3-D reconstruction. Naturwissenschaften. 2014;101:467–77. https://doi.org/10.1007/s00114-014-1176-0.
2. Bergquist PR, Ayling AM, Wilkinson CR. Foliose Dictyoceratida of the Australian Great Barrier Reef. I. Taxonomy and phylogenetic relationships. Mar Ecol. 1988;9:291–319. https://doi.org/10.1111/j.1439-0485.1988.tb00209.x.
3. Erpenbeck D, Sutcliffe P, Cook SDC, Dietzel A, Maldonado M, van Soest RWM, et al. Horny sponges and their affairs: on the phylogenetic relationships of keratose sponges. Mol Phylogenet Evol. 2012;63:809–16. https://doi.org/10.1016/j.ympev.2012.02.024.
4. Pham D, Hong J, Lee JH. Keratose sponge–microbial consortia in stromatolite-like columns and thrombolite-like mounds of the Lower Ordovician (Tremadocian) Mungok Formation, Yeongwol, Korea. Palaeogeogr Palaeoclimatol Palaeoecol. 2021;572: 110409. https://doi.org/10.1016/j.palaeo.2021.110409.
5. Morrow C, Cárdenas P. Proposal for a revised classification of the Demospongiae (Porifera). Front Zool. 2015;12:1–27. https://doi.org/10.1186/s12983-015-0099-8.
6. de Voogd NJ, Alvarez B, Boury-Esnault N, Carballo JL, Cárdenas P, Díaz M-C, Dohrmann M, Downey R, Hajdu, E, Hooper JNA, Kelly M, Klautau M, Manconi R, Morrow CC, Pisera AB, Ríos P, Rützler K, Schönberg C, Vacelet J, van Soest RWM. 2023. World Porifera Database. https://www.marinespecies.org/aphia.php?p=taxdetails&id=366651. Accessed 19 Apr 2023.
7. Carter HJ. Report on specimens dredged up from the Gulf of Manaar and presented to the Liverpool Free Museum by Cap. W.H. Cawne Warren. J Nat Hist. 1880;6:35–61. https://doi.org/10.1080/00222938009458893.
8. Carter HJ. Supplementary report on Specimens dredged up from the Gulf of Manaar, together with others from the Sea in the Vicinity of the Basse Rocks and from Bass's Straits respectively, presented to the Liverpool Free Museum by Capt. H. Cawne Warren. J Nat Hist. 1881;7:361–85. https://doi.org/10.1080/00222938109459534.
9. Dendy A. The Sponge-fauna of Madras. A report on a collection of sponges obtained in the neighbourhood of Madras by Edgar Thurston, Esq. Ann Mag Nat Hist. 1887;20:153–65. https://doi.org/10.1080/00222938709460032.
10. Dendy A. Report on the sponges collected by Professor Herdman, at Ceylon, in 1902, In: Herdman WA, editor. Report to the Government of Ceylon on the Pearl Oyster Fisheries of the Gulf of Manaar. 3 (Supplement 18), Royal Society, London; 1905. pp. 57–246, pls I–XVI.
11. Burton M. Supplement to the littoral fauna of Krusadai Island in the Gulf of Manaar: Porifera (Vol. 1, No. 2). Bulletin of the Madras Government Museum, Superintendent, Government Press; 1937.
12. Rao HS. Indian and Ceylon sponges of the Naturhistoriska Riksmuseet, Stockholm, collected by K. Fristedt. Rec Zool Surv India. 1941;43:417–69.
13. Thomas PA. Demospongiae of the Gulf of Mannar and Palk Bay. In: James PSBR, editor. Recent advance in marine biology. New Delhi: Today Tomorrow's printers and publishers; 1985. p. 205–365.
14. Sivaleela G. Marine sponges of Gulf of Mannar and Palk Bay. Rec Zool Surv India. 2014;114:607–22.
15. von Lendenfeld R. A monograph of the horny sponges. London: Trübner and Co.; 1889. p. 1–936.
16. Dendy A. Report on the non-Calcareous Sponges collected by Mr. James Hornell at Okhamandal in Kattiawar in 1905–6. Report to the Government of Baroda on the Marine Zoology of Okhamandal in Kattiawar. 1916; 2: 93–146, pls I–IV.
17. Subba Rao NV, Sastry DRK. Fauna of Marine National Park, Gulf of Kutch (Gujarat): An overview. Conservation Area Series 23, 1–79, pls I–VIII. (Published by the Director, Zoological Survey of India, Kolkata; 2005.
18. Thomas PA. Demospongiae of Minicoy Island (Indian Ocean) Part 1 – Orders Keratosa and Haplosclerida. J Mar Biol Assoc India. 1979;21:10–6.
19. Thomas PA. Sponge fauna of Lakshadweep. Bull Cent Mar Fish Res Inst. 1989;43:150–61.
20. Prabhakaran MP. Ecological studies on the seagrass ecosystem of Minicoy Lagoon Lakshadweep. Ph.D. Thesis, Cochin University of Science and Technology; 2008.
21. Gopi M, Kumar TTA. Sponge Fauna of Lakshadweep Archipelago. Seshaiyana. 2012;20:3–5.
22. Dam Roy S, Krishnan P, Raghunathan C, Vinith Kumar NV. Cataloguing and Conservation of Marine Sponges of Andaman through DNA Barcoding. Project Completion Report, Port Blair; 2013.
23. Immanuel T, Krishnan P, Raghunathan C. An updated report on the diversity of marine sponges of the Andaman and Nicobar Islands. In: Sivaperuman C, Venkataraman K, editors. Marine faunal diversity in India: taxonomy, ecology and conservation. Amsterdam, Cambridge: Elsevier, Academic press; 2015. p. 3–13.
24. Das RR, Immanuel T, Lakra RK, Baath K, Ganesh T. First report of marine sponge *Chelonaplysilla delicata* (Demospongiae: Darwinellidae) from the Andaman Sea/Indian Ocean with baseline information of epifauna on a mesophotic shipwreck. J Threat Taxa. 2022;14:21961–7. https://doi.org/10.11609/jott.7495.14.10.21961-21967.
25. George AM, Van Soest RW, Sluka RD, Lazarus S. A checklist of marine sponges (Porifera) of peninsula India. Zootaxa. 2020;4885:277–300. https://doi.org/10.11646/zootaxa.4885.2.10.
26. Spalding MD, Fox HE, Allen GR, Davidson N, Ferdaña ZA, Finlayson MAX, Halpern BS, Jorge MA, Lombana AL, Lourie SA, Martin KD. Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. Bioscience. 2007;57:573–83. https://doi.org/10.1641/B570707.
27. Shorthouse DP. SimpleMappr, an online tool to produce publication-quality point maps. 2010; https://www.simplemappr.net. Accessed 19 Aug 2023.
28. Bandopadhyay PC, Carter A. Introduction to the geography and geomorphology of the Andaman-Nicobar Islands. Geol Soc London. 2017;47:9–18.
29. Tikader BK, Das AK. Glimpses of animal life of Andaman and Nicobar Islands. Calcutta: Zoological Survey of India; 1985.

30. Laxmilatha P, Sruthy TS, Varsha MS. Marine protected areas. In: Joshi KK, editor. Summer school on recent advances in marine biodiversity conservation and management. Kochi: Central Marine Fisheries Research Institute; 2015. p. 199–206.
31. Ackers RG, Moss D, Picton BE, Stone SM, Morrow CC. Sponges of the British Isles ("Sponge V")—a colour guide and working document. Belfast: Marine Conservation Society/Ulster Museum; 2007.
32. Slaoui M, Fiette L. Histopathology procedures: from tissue sampling to histopathological evaluation. In: Gautier JC, editor. Drug safety evaluation. Methods in molecular biology (methods and protocols), vol. 691. Humana Press: New York; 2011. p. 69–82. https://doi.org/10.1007/978-1-60761-849-2_4.
33. Hooper JNA, Van Soest RW, editors. Systema Porifera. A guide to the classification of sponges. New York: Kluwer Academic/ Plenum Publishers (Springer); 2002. https://doi.org/10.1007/978-1-4615-0747-5.
34. de Cook SC, Bergquist PR. Family Thorectidae Bergquist, 1978. In: Hooper JNA, Van Soest RW, editors. Systema Porifera. Boston: Kluwer Academic/Plenum Publishers, Springer; 2002. p. 1028–50.
35. Bergquist PR. The sponges of micronesia, Part I. The Palau Archipelago Pac Sci. 1965;19:123–204.
36. Bergquist PR, de Cook SC. Family Dictyodendrillidae Bergquist, 1980. In: Hooper JNA, Van Soest RW, editors. Systema Porifera. Boston: Kluwer Academic/Plenum Publishers, Springer; 2002. p. 1072–6.
37. Bergquist PR. A revision of the supraspecific classification of the orders Dictyoceratida, Dendroceratida and Verongida (class Demospongiae). N Z J Zool. 1980;7:443–503. https://doi.org/10.1080/03014223.1980.11760680.
38. von Lendenfeld R. Descriptive catalogue of the sponges in the Australian Museum, Sidney. London: Taylor and Francis; 1888. p. 1–260.
39. Hosie AM, Fromont J, Munyard K, Wilson NG, Jones DS. Surveying keratose sponges (Porifera, demospongiae, Dictyoceratida) reveals hidden diversity of host specialist barnacles (Crustacea, Cirripedia, Balanidae) Mol. Phylogenet Evol. 2021;161: 107179. https://doi.org/10.1016/j.ympev.2021.107179.
40. Bowerbank JS. Report on a Collection of Sponges found at Ceylon by E.W.H. Holdsworth, Esq. Proc Zool Soc Lond.1873; 25–32, pls V–VII.
41. Hyatt A. Revision of the North American Poriferae; with Remarks upon Foreign Species. Part II. Memoirs of the Boston Society of Natural History. 1877; 2:481–554, pls XV–XVII.
42. Desqueyroux-Faúndez R. Sponges (Demospongiae) from Easter Island (Isla de Pascua) (South Pacific Ocean). Rev Suisse Zool. 1990;97:373–410.
43. Thiele J. Studien über pazifische Spongien. II. Ueber einige Spongien von Celebes. Zoologica. Original-Abhandlungen aus dem Gesamtgebiete der Zoologie. Stuttgart. 1899; 24: 1–33, pls I–V
44. Lévi C. Spongiaires des Iles Philippines, principalement récoltées au voisinage de Zamboanga. Philipp J Sci. 1961;88:509–33.
45. Bergquist PR, Morton JE, Tizard CA. Some Demospongiae from the Solomon Islands with descriptive notes on the major sponge habitats. Micronesica. 1971;7:1–2.
46. Bergquist PR. Dictyoceratida, Dendroceratida and Verongida from the New Caledonia Lagoon (Porifera: Demospongiae). Mem Queensl Mus. 1995;38:1–51.
47. Hooper JNA, Wiedenmayer F. Porifera. In: Wells A, editor. Zoological catalogue of Australia, vol. 12. Melbourne: CSIRO; 1994.
48. Ridley SO. Spongiida. Report on the Zoological Collections made in the Indo-Pacific Ocean during the Voyage of H.M.S. 'Alert', 1881–2. (British Museum (Natural History): London). 1884; 366–482, pls 39–43; 582–630, pls 53–54.
49. Lévi C. Résultats scientifiques des Campagnes de la 'Calypso'.Campagne 1951–1952 en Mer Rouge (suite). 11. Spongiaires de Mer Rouge recueillis par la 'Calypso' (1951–1952). Annales de l'Institut océanographique. 1958; 34: 3–46.
50. Lévi C. Résultats scientifiques des Campagnes de la 'Calypso'. Campagne 1954 dans l'Océan Indien (suite). 2. Les spongiaires de l'Ile Aldabra. Annales de l'Institut océanographique. 1961; 1–32, pls 1–2.
51. Vacelet J, Vasseur P. Spongiaires des grottes et surplombs des récifs de Tuléar (Madagascar). Recueil des Travaux de la Station marine d'Endoume. 1965;2–4:71–123.
52. Helmy T, El Serehy H, Mohamed SZ, Van Soest RWM. Description and classification of dictyoceratid sponges from the northern Red Sea. Beaufortia. 2004;54:81–91.
53. Pereira P, Raghunathan C. Diversity of sponges in marine protected areas of North Andaman, India. Thalassas. 2018;34:361–72. https://doi.org/10.1007/s41208-018-0073-2.

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