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Morphological traits and spatial distribution of azooxanthellate corals of Rhizangiidae in the Laccadive Sea

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Abstract

Azooxanthellate corals of Rhizangiidae, with their distinctive morphological and ecological features, are widely distributed across global oceans but remain under-studied due to identification challenges. Comprehensive underwater surveys across diverse marine habitats such as rocky reefs and submerged shipwrecks were undertaken, and findings highlighted the exclusive presence of *Culicia stellata* in natural rocks, off the coast of Kaup for the first time in Indian EEZ. The study also records the presence of *Cladangia exusta,* nearly six decades after the first record from off Cochin, Laccadive Sea. This research presents a detailed study of the taxonomic description, distribution, and ecological preferences of *Cladangia exusta* and *Culicia stellata* in the Laccadive Sea. This study underscores the importance of accurate species identification for effective conservation strategies and enriching biodiversity records.

Introduction

Research on cnidarian diversity has gained significant attention due to their crucial ecological roles in marine ecosystems. Among cnidarians, Scleractinian corals have been of particular importance, given their central role in coral reef ecosystems and the profound impacts that climate change is expected to have on their survival and associated biodiversity. The evolutionary success of Scleractinian corals is primarily linked to their symbiotic association with photosynthetic dinoflagellates of the family Symbiodiniaceae (Vuleta *et al*., 2024). However, not all Scleractinian corals have symbiosis with dinoflagellate and those that do not, are broadly categorized as azooxanthellate corals (Cairns, 1999). These corals are exclusively heterotrophic, obtaining nutrients from the surrounding water column, including organic matter, phytoplankton, and zooplankton (Houlbrèque *et al*., 2015). Azooxanthellate corals host diverse microbial assemblages that plays vital role in nutrient cycling (Houlbrèque *et al*., 2015). Even when azooxanthellate corals covers nearly half of the known Scleractinian diversity globally, their distribution, life history traits and ecological role are less studied compared to their photo endosymbiotic counterparts. Research on azooxanthellate corals is limited, primarily due to the perceived lack of environmental significance, insufficient information on potential environmental threats and ecosystem complexities in which they occur.

Globally, azooxanthellate Scleractinian corals are distributed across 14 families (Cairns, 2004; Cairns and Kitahara, 2012). However, only four families—Caryophyllidae, Flabellidae, Rhizangiidae, and Dendrophyllidae—have been documented in Indian waters (Singarayan and Rethnaraj, 2016). While the environmental, ecological, and socio-economic significance of coral reefs is well recognized, early research on coral taxonomy in India predominantly focused on zooxanthellate, or photosymbiotic scleractinian corals, with limited attention given to azooxanthellate species (Pillai, 1967b; Venkataraman *et al*., 2003). In recent years, there has been an increasing awareness of the need for comprehensive studies on all vulnerable coral species, regardless of their symbiotic status. This has led to a surge in research focusing on azooxanthellate corals in Indian waters (Singarayan and Rethnaraj, 2016; Viswambharan *et al*., 2021; Mondal and Raghunathan, 2022), with particular emphasis on the taxonomy and distribution of species within the families Caryophyllidae, Flabellidae, and Dendrophyllidae.

The family Rhizangiidae, a subgroup within the azooxanthellate Scleractinia, is among the least studied groups of azooxanthellate corals, both in India and globally. Species within this family are characterized by small, encrusting colonies of corallites that are interconnected at their bases. Nearly six decades ago, two species of azooxanthellate Rhizangiids, *Cladangia exusta* and *Culicia rubeola*, were documented in Indian waters (Pillai, 1967a, 1967b). Despite numerous studies conducted in various coastal ecosystems following Pillai's work, these species have not been recorded in Indian coastal waters. The under-documentation of Rhizangiid corals is often attributed to their small size, challenges in morphological identification, and the lack of information on their ecological preferences. Conservation efforts are further hampered by a lack of comprehensive data on their distribution, taxonomy, and ecology. This study was therefore undertaken to rediscover these Rhizangiid corals, map their distribution, and identify

Table 1. Details on sampling sites and sampling period

Survey site	Survey period
Netrani Island (off Murudeshwara)	May 2018, December 2018, November 2019, December 2019, January 2020, December 2020, November 2021, January 2022, December 2022
Hog Island (off Bhatkal)	December 2020
Bhatkal Wreck (off Bhatkal)	December 2020
Mulki Rocks (off Kaup)	May 2018, November 2019, January 2020, December 2020, November 2021, December 2022
Wreck (off Kaup)	May 2018, January 2020, March 2020, November 2021, December 2022
St. Mary's Island (off Malpe),	March 2023
Rocky Reef (Off Paduthonse)	March 2023

their ecological preferences along the southwest coast of India, with a special focus on documenting their morphological diagnostic characteristics.

The coastal waters of the southwest coast of India (northeastern Laccadive Sea) were selected for this study, as these regions were the first to record these corals in India. Comprehensive underwater surveys were conducted across diverse marine habitats, including rocky reefs and submerged shipwrecks. These surveys led to the identification of two Rhizangiid coral species in the coastal water ecosystem. Given the challenges of accurately identifying these corals, efforts were made to delineate distinct morphological traits to effectively differentiate them from other azooxanthellate corals with similar morphology and habitats.

Materials and Methods

A comprehensive series of exploratory surveys were undertaken across diverse marine habitats encompassing rocky reefs, coral reefs, inshore islands, and submerged shipwrecks within the expanse of the Laccadive Sea. Employing SCUBA-assisted underwater visual census techniques, observations were carried out to document the distribution patterns of Rhizangiid corals in specific locales, namely Netrani Island (off Murudeshwara), Hog Island (off Bhatkal), Bhatkal Wreck (off Bhatkal), Mulki Rocks (off Kaup), a shipwreck site (off Kaup), St. Mary's Island (off Malpe), and the rocky reef in vicinity of Paduthonse. Details of exploratory surveys conducted are given in Table 1.

During the underwater survey, live coral specimens were documented *in situ* using a Nikon Coolpix W300 camera. To ensure accurate species identification, coral specimens were collected from two locations: Mulki Rocks (off Kaup, Dakshina Kannada, Karnataka) and a submerged shipwreck site (off Bhatkal, Uttara Kannada, Karnataka). The collected specimens were soaked in freshwater, meticulously cleaned using a fine-bristle brush, and subsequently air-dried at room temperature. Detailed morphological features of the coralla were then photographed using a stereoscopic microscope. Species identification was carried out using relevant scientific literature, including Dana (1846), Lütken (1873), Pillai (1967a, 1967b), Cairns and Zibrowius (1997), Cairns (2004), and Viswambharan *et al.* (2021). Additionally, information on the distribution of Rhizangiid corals was corroborated using previously published sources (Pillai, 1967a, 1967b; Cairns, 2004).

Georeferenced data were collected during field surveys using GPS devices to accurately capture the location of coral colonies. Additionally, location data from existing literature were compiled to ensure a comprehensive dataset. The integrated data were then used to generate a spatial map in NextGIS QGIS.Ink (version 23.11.0).

Results

The comprehensive survey, recorded the presence of *Culicia stellata* and *Cladangia exusta* in the Laccadive Sea, and this finding is a significant contribution to the limited knowledge of Rhizangiid corals in Indian waters. Our study documents the presence of *Cladangia exusta* in the Laccadive Sea, nearly six decades after its initial observation in 1967. Additionally, the discovery of *Culicia stellata* is particularly noteworthy as it represents the first recorded occurrence of this species within the Indian Exclusive Economic Zone (EEZ).

***Cladangia exusta* Lütken, 1873** (Figure 1)
Systematics
Order: Scleractinia Bourne, 1900
Family: Rhizhangiidae d'Orbigny, 1851
Genus: *Cladangia* Milne Edwards & Haime, 1851
Species: *Cladangia exusta* Lutken, 1873
Recorded locality: Bhatkal Wreck, off Bhatkal, Karnataka State, India. Depth: 30–32 m

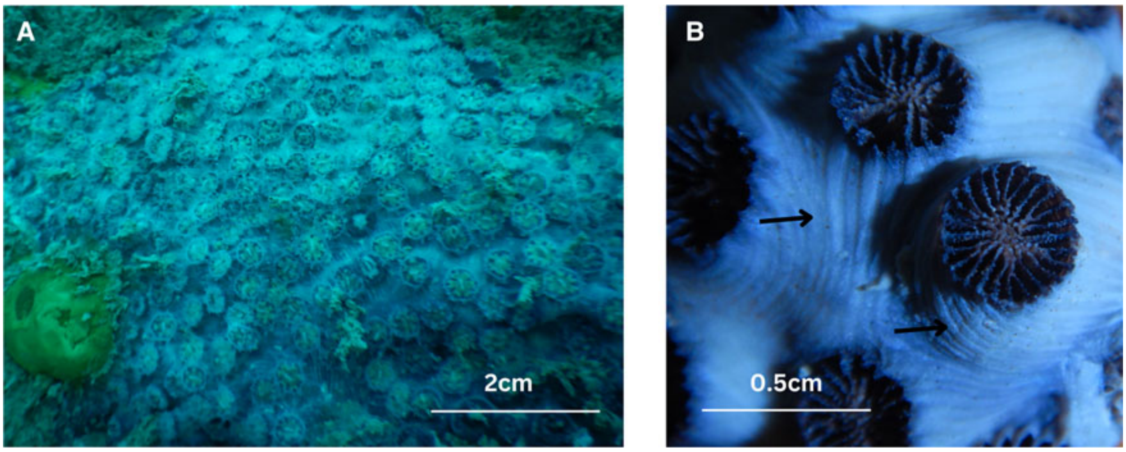

Figure 1. (A) Live photographs of *Cladangia exusta* Lütken, 1873 in Bhatkal Wreck. (B) Calicular view showing the septal size and arrangement in corallites (black arrows showing the costae ridges in the inter-corallite area).

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Table 2. Diagnostic characters of *Cladangia exusta* Lütken, 1873

Diagnostic characters	Present study	Lütken, 1873	Pillai, 1967	Cairns, 2004
Colony	Encrusting and massive. Nearly 18 corallites are observed in the present sample.	Irregular, round, tuber like mass of 3–3.5-inch diameter and 1.25-inch height	Encrusting, massive, or sub-ramose	Plocoid, consisting of 15–17 corallites
Corallites	Calices circular to slightly oval; 3–4.6 mm diameter. The height of the corallites is 0–2 mm	Roughly circular or slightly elongated cups with a diameter around 5 mm.	Corallites projecting to a maximum of 2 mm, generally about 1 mm. Calices rounded, rarely slightly oval, 3–3.5 mm in diameter rarely up to 5 mm in diameter and very shallow	Circular, cylindrical, and low (up to 1.7 mm). largest corallite is 4.1 mm in diameter.
Distance between corallites	The spacing between the corallite varied. Some corallites are closely located but distance between a few is quite large, even greater than cup diameter of the largest corallite.	Differently spaced. Hither and thither 2–3 corallites stood next to each other, in other places, the distance is large, i.e. greater than cup measure, but generally somewhat less than this.	2–5 mm	Closely spaced (adjacent to 1.2 mm apart)
Coenosteum	Firm and dense. Costae ridges are clearly seen over the inter-corallite area but become faint and obsolete and they do not show any fusion. The inter corallite ridges are very clearly visible in live specimens too.	Firm, and resembles porcelain in bluish or yellowish white colour. The surface is finely grained and ribs are recognizable in space between the cups.	Dense, and is in dull grey colour. Costae ridges are seen over the inter-corallite area but become faint and obsolete towards the centre, generally not showing any actual fusion among themselves	Firm
Columella	Papillose. The top of the columella being only less than a mm. below the level of the thecal rim or generally level.	'Papillo-spongiosus', formed by the intergrowth and intertwining of the central outgrowths and extensions of the septa.	Columella prominent, essentially trabecular with 9 or 10 papillary projections which merges with the septal dentition. The top of the columella being only less than a mm. below the level of the thecal rim or generally level.	Papillose
Costae	Costae correspond to septa, extend to the base of the corallites	Ribbed, ribs are flat and rounded separated by fine furrows.	Costae correspond to septa, extend to the base of the corallites; low but round topped, thicker than intercostal spaces.	Granular
Colour of the colony (cleaned and dried)	The coenosteum and theca are bluish white. The interior of the calice, the septa and columella appear shades of blackish brown.	Coral polyp cell is black-brown and Coenosteum is bluish or yellowish white	The interior of the calyx, the septa and columella appear chocolate brown. Coenosteum and outer wall of the theca dull grey	White corallum
Number of septa and septal arrangement	Septa in three complete cycles. Septa very thin and only primary septa are slightly exsert. Septa of the first two cycles directly extend to the columella. The septa of the 3rd cycle fuse to the sides of the second cycle just before the latter reach the columella. Faces of septa have well-developed granulations. The thickness of the septa of all the cycles are almost similar.	Number of septa is 24 or more, which can rarely be much higher up to 42. The size difference of septa is insignificant. Six primary and secondary septa and twelve tertiary septa are developed (total 24), and that the tertiary ones do not continue all the way to the columella, but bend off in front towards the secondary ones and unite with them; to these 24 are added in many cases a greater or lesser number of septa of a fourth incompletely developed circuit.	Septa in three complete cycles (one giant calyx with 36 septa); higher and lower cycles not prominently distinct, but in a few calices the primaries a bit more thickened. Septa very thin, inter-septal loculi about twice the thickness of the septa. Septa not exsert, but beginning from the top of the wall; faces of septa with well-developed granulations. Primary septa with 3 to 4 teeth towards their lower part, higher cycles with lesser numbers. First two cycles of septa directly extend to the columella, the members of the third fuse to the sides of the second cycle just before the latter reach the columella.	Septa hexamerally arranged in 4 incomplete cycles, the largest corallite having 36 septa, or 1 pair of S4 in each system. S1 independent, bearing 1–3 discrete, rounded paliform lobes on their axial edges. S2 smaller, also bearing 2–3 rounded lobes. Axial edges of S3 loosely fuse to adjacent S2; axial edges of S4 fuse to adjacent S3.

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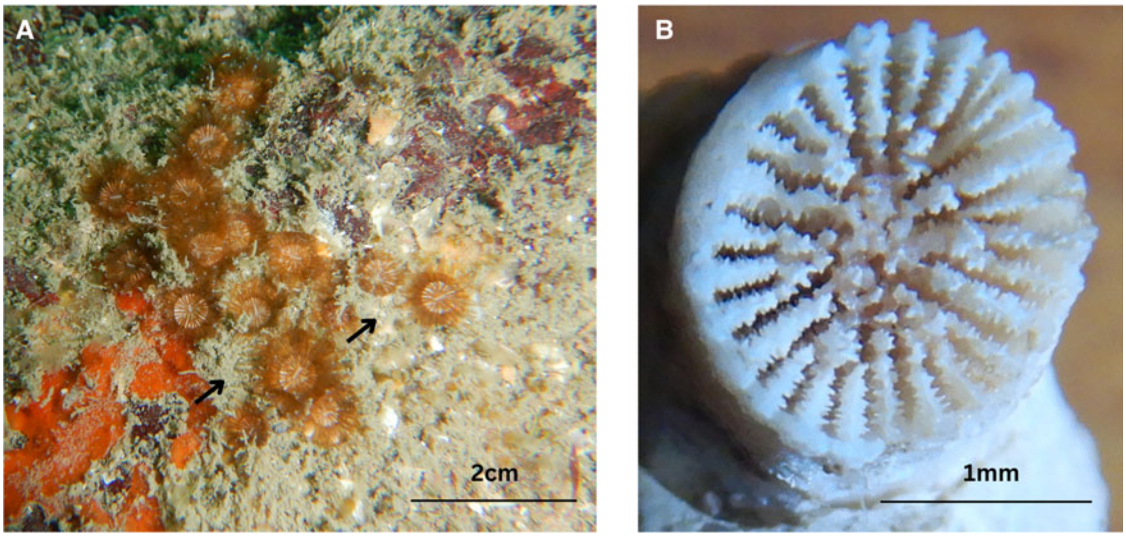

Figure 2. (A) Live photographs of *Culicia stellata* Dana, 1846 in Mulki Rocks (black arrows shows the solan covered by epifauna). (B) Calicular view showing the septal size and arrangement in corallites.

Remarks: Previously recorded from off-Cochin, Laccadive Sea and in Moreton Bay (Queensland). Details on the exact location and depth of occurrence are not available in the previous studies (Pillai, 1967a; Cairns, 2004). In Indian EEZ, the species was found to grow over submerged metal surfaces.

Species Characteristics: Details about this species, including species description based on their morphological traits are outlined in Table 2.

Distribution: Coastal waters of Indian EEZ (Laccadive Sea-Indian Ocean); Queensland (Moreton Bay- Pacific Ocean)

***Culicia stellata* Dana, 1846** (Figure 2)

Systematics

Order: Scleractinia Bourne, 1900

Family: Rhizhangiidae d'Orbigny, 1851

Genus: *Culicia* Dana, 1846

Species: *Culicia stellata* Dana, 1846

Recorded locality: Mulki Rocks, Off Kaup, Karnataka State, India. Depth: 6–8 m.

Remarks: The habitat preference of *Culicia* seems to be natural substances like rocks or dead corals in shallow water with high turbidity. First record from Indian EEZ. The species is recorded in the atolls of Maldives in the Laccadive Sea.

Species Characteristics: Details about this species, including species description based on their morphological traits are outlined in Table 3.

Distribution: Coastal waters of Indian EEZ (Laccadive Sea-Indian Ocean), West and Central Pacific Ocean

Table 3. Diagnostic characters of *Culicia stellata* Dana, 1846

Diagnostic characters	Present study	Cairns and Zibrowius, 1997
Colony	Consist of 18 corallites, reptoid. Solan linking the corallites are thin and are covered by epifauna	Consisting of 50–60 corallites produced by extra-tentacular, reptoid budding. Stolon linking the corallites thin and flat. Stolon covered by encrusting epifauna
Corallites	Corallite circular to elliptical in cross section. GCD ranged 1.81–3.71 mm Height ranged 2.58–5.16 mm	Corallites circular to slightly elliptical in cross section, up to 3.8 mm in GCD, and 4.3 mm in height
Distance between corallites	The spacing between the corallite varied. the distance varied from 0.01 mm to 7 mm	1–5 mm
Columella	Papillose consisting of 9–10 elements, similar in shape and size of paliform teeth of septa	Papillose consisting of 5–9 elements, similar in shape and size of innermost septal teeth
Epitheca	Very thin, smooth and translucent.	Very thin, almost translucent, smooth upper rim that raise above the outer septal edges. (Observed in well preserved samples)
Colour of the colony	White (when cleaned and dried) In live condition, the colour of the colony and the polyp is ochreous	Not mentioned In the original description by Dana, 1846, the colour is described as pale ochreous
Number of septa and septal arrangement	Septa hexamerally arranged in 4 cycles and last cycle is never complete. Number of septa ranged 26–32. S1 is independent while septa of the 3rd cycle fuse to the sides of the second cycle. S1 and S2 have paliform lobes. The paliform lobes of S2 is formed in front of the point where S2 fuses with two S3. S4 is rudimentary and the 4th cycle is not complete in any of the corallites. Inner edge of the septa is slightly vertical	Septa hexamerally arranged in 4 cycles, the last cycles never complete, 34–42 being the most common septal complement. S1 independent, each composed of a tall but narrow upper lobe, a vertical inner edge and 1 or 2 laciniate teeth on its lower, inner margin. S2–3 equal in size and shape, the inner edges of the 2 S3 and 1 S2 in each system fusing near the columella. S2–3 not lobate as the S1, but bearing 3 or 4 laciniate teeth that grade into the columellar elements. S4 rudimentary, consisting of a discontinuous row of spines, each 1/3 to ¼ height of the adjacent lower cycle septum.

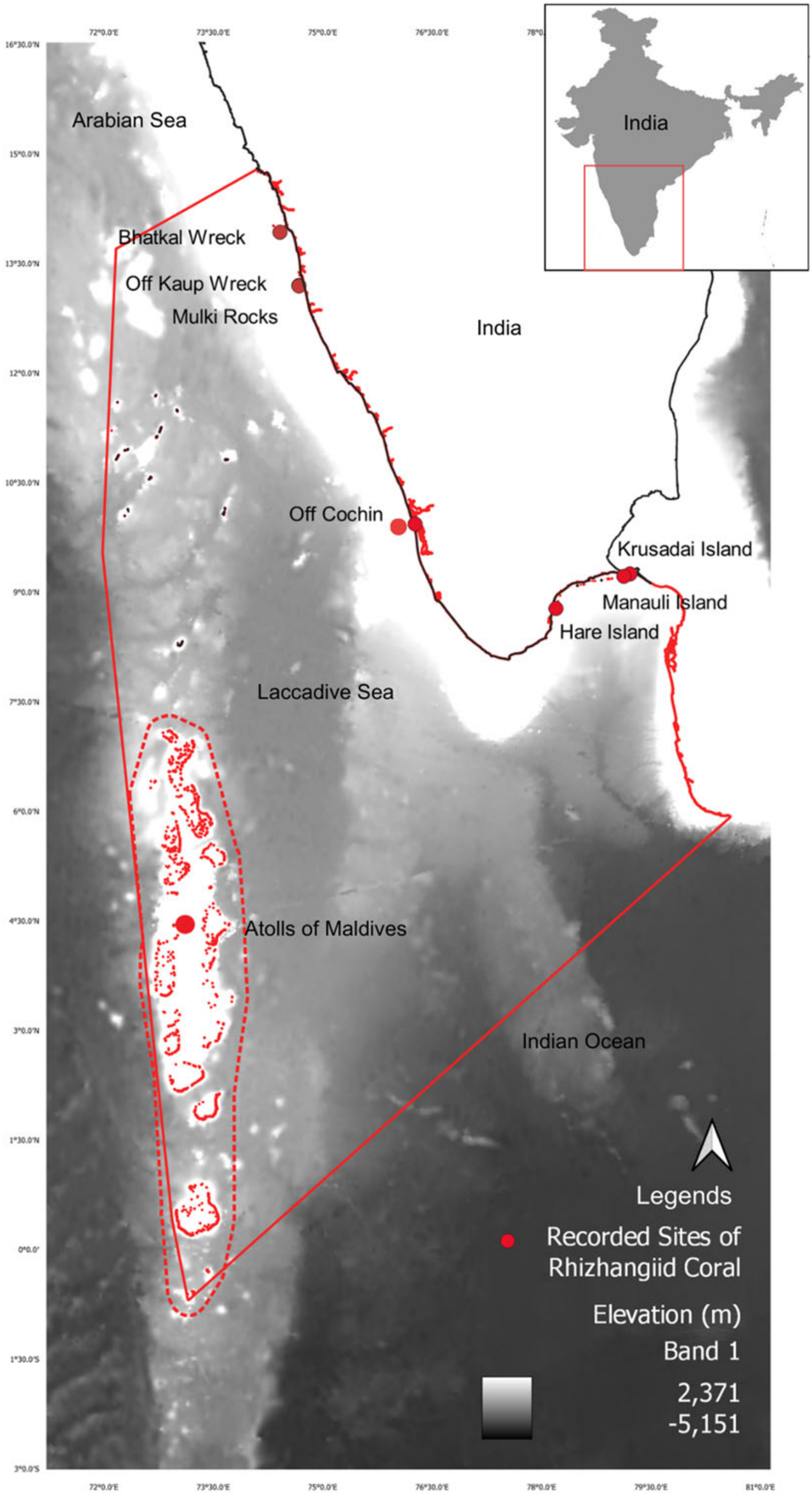

Figure 3. Map showing the distribution of Rhizangiid corals in Laccadive Sea.

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Discussion

Despite the ecological importance of azooxanthellate corals, particularly Rhizangiids, significant gaps remain in our understanding of their distribution in the Laccadive Sea. These gaps are largely due to limited survey efforts and the challenges posed during species identification, which arise from their small colony sizes and complex morphology. This lack of comprehensive data hinders the development of effective conservation and management strategies for these marine organisms. To date, only two Rhizangiid species have been documented in Indian waters: *Cladangia exusta* (Pillai, 1967a) from the waters off Cochin and *Culicia rubeola* (Pillai, 1967b) from three islands in the Gulf of Mannar. Our study addresses this critical knowledge gap by documenting the presence of *Culicia stellata* for the first time within the Indian EEZ and expanding the known range of *C. exusta* beyond shallow coastal waters.

In the family Rhizangiidae, the genus *Culicia* possess significant challenges in species delineation, necessitating thorough review and revision. The morphological characteristics used to identify *Culicia stellata* are discussed in Table 3. Prior studies in the Gulf of Mannar had recorded *Culicia rubeola* from Krusadai Island, Manauli Island, and Hare Island, where the species was found on natural rocks as well as dead *Porites* spp (Pillai, 1967b). *Culicia stellata* can be distinguished from *C. rubeola* by the differences in the septal lobes, where the septal lobes in *C. stellata* are observed only in the S1, while in *C. rubeola*, S1, S2, and S3 are lobed (Cairns, 1995; Cairns and Zibrowius, 1997).

The map on the recorded distribution of azooxanthellate corals of Rhizangiidae in Laccadive Sea are shown in Figure 3. Interestingly, these corals are uncommonly recorded in well-established coral reef locations within the Laccadive Sea, including the Laccadive atolls or the coral reefs surrounding Netrani. Despite comprehensive survey efforts, the occurrences of these corals were restricted to Mulki Rocks, as well as submerged shipwrecks situated off Bhatkal. Multiple colonies of *Culicia stellata* were exclusively observed on Mulki rocks, off the coast of Kaup in Karnataka. These live colonies, found at depths ranging from 6 to 8 meters, were surrounded by encrusting epifauna to such an extent that the stolon of the colony was fully concealed. Finding these corals were difficult due to their minuscule size and the presence of epifauna that nearly concealed each of their tiny corallites. This study had shown that *Culicia* preferred coastal rocky/coral reef areas and are unaffected by high turbidity. The colonies were predominantly located on the upper surfaces of rocks, where sufficient light penetration occurred during post monsoon season but visibility falls to less than one meter during the pre-monsoon and monsoon season.

Present survey has recorded the occurrence of *Cladangia exusta* in the submerged wreck, off-Bhatkal in Karnataka in the south west coast of India (north eastern Laccadive Sea). A thorough literature review was undertaken and distinctive feature of *Cladangia exusta* are given in Table 2. Since *Astrangia* and *Cladangia* are often confused and misidentified in Indian Coast, the discriminative attributes demarcating *Astrangia woodsi* from *Cladangia exusta* are elucidated in Table 4. Three live colonies of *Cladangia* were observed on the starboard side of the wrecked ship. The site is a fishing ground for off shore vessels, mainly purse seiners. The site was highly turbid with visibility limited to less than 0.5 m in February–May (pre-monsoon). The corals were surrounded by hydroid (*Aglaophenia* sp) and few unidentified sea anemones. The earlier study conducted by Pillai (1967a) had identified the species on a submerged metal piece but specific details on the location of sample collection and depth of its occurrence were not recorded. This observation marks the reporting of live *Cladangia exusta* in the Laccadive Sea since its first discovery nearly six decades ago within the coastal waters off Cochin. The historical research conducted by Lütken (1873) had initially constrained habitat of *Cladangia* to littoral regions; however, present day findings indicate that the species might exhibit a broader distribution extending into deeper waters, contrasting with Lütken's original assertion.

The habitat preference of the Rhizangiid coral *Cladangia exusta* appears to be somewhat atypical. In this study, live colonies of *C. exusta* were observed at a depth of 30–32 m on a submerged shipwreck (Figure 1a). Although these three colonies were well-established on the wreck, no occurrences of *C. exusta* were found on natural rocky substrates at similar depths. Despite extensive surveys conducted during the research period, *C. exusta* was consistently absent from natural rock formations. Coral habitat preference is initially influenced by broad environmental cues that help identify suitable habitats. Upon contacting a surface, corals detect chemical cues, such as biotic signals or external biochemicals, which indicate habitats where successful recruitment has previously occurred (Price, 2010). Notably, *C. exusta* seems to exhibit a distinct preference for submerged metallic structures. This inclination is supported by both the findings of this survey and the initial record by Pillai (1967a), which documented the species exclusively in association with submerged metal. But more studies are required to determine whether this preference for submerged metallic structures is a consistent ecological trait of *Cladangia exusta* or if it represents an adaptive response to specific environmental conditions. Hence further investigations are essential to better understand the habitat preferences and ecological requirements of *Cladangia exusta*.

This study on *Culicia stellata* and *Cladangia exusta* within the Indian EEZ significantly enhances the global understanding of azooxanthellate corals in the family Rhizangiidae, advancing both taxonomic and ecological knowledge through detailed descriptions of their morphological characteristics and habitat

Table 4. Difference between *Astrangia woodsi* Wells, 1955 and *Cladangia exusta* Lütken, 1873 found in coastal area along the west coast of India

Distinguishing characters	*Cladangia exusta* Lütken, 1873 (Family: Rhizangiidae) (Present Study)	*Astrangia woodsi* Wells, 1955 (Family: Astrangiidae) (Viswambharan *et al*., 2021)
Colour of the colony and corallites	In live condition (underwater), the colony appears light coloured. In cleaned dried colony, the coenosteum and theca are bluish white/ Gray. The interior of the calice, the septa and columella appear shades of blackish brown	In live condition (underwater), the entire colony is dark/black coloured. The entire colony (including coenosteum, theca, corallum and calice) is black and retains the colour after cleaning
Coenosteum	Firm and dense. Costae ridges are clearly seen over the inter-corallite area but become faint and obsolete and they do not show any fusion. The inter corallite ridges are very clearly visible in live colony	Conspicuous, thin, smooth to slightly granular and continuous The inter corallite space is smooth in live colony
Columella	Conspicuous and papillose	Inconspicuous and papillose
Septa	The thickness of septa almost remains the same across cycle.	The thickness of the septa decreases with cycle.

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preferences. Our findings aid in facilitating easier identification and monitoring of these species, which is crucial for developing effective conservation strategies and conducting comprehensive biodiversity assessments. The study also underscores the importance of habitat diversity in sustaining the rich marine life within the Indian EEZ, a paramount aspect of global marine biodiversity conservation efforts (Bellwood *et al*., 2004; Foster *et al*., 2013).

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Data availability statement. The data that support the findings of this study are available from the corresponding author, DV, upon reasonable request.

Author contribution. DV- diving, sampling, photography, mapping, species taxonomy, literature review, and writing (original draft); SKR – writing (original draft, review and editing).

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Competing interest. The authors declare no conflict of interest.

Ethical standards. No animal testing was performed during this study.

Sampling and field studies. All necessary permits for sampling and observational field studies have been obtained by the authors from the competent authorities and are mentioned in the acknowledgments. The study is compliant with CBD and Nagoya protocols.

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