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## The hard corals (Scleractinia) of India: A revised checklist

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Persistence of coral reefs is threatened globally due to intensified human activities and ongoing climate change. Coral reefs in India are also suffering from acute stress events like mass coral bleaching and coastal development activities, which has led some of the coral species on the verge of local extinction. Here, we present a revised checklist of scleractinian corals from the major Indian reefs, namely Gulf of Kachchh (GoK), Lakshadweep Islands (LI), Gulf of Mannar Marine Biosphere Reserve (GoMBR), and Andaman and Nicobar Islands (ANI), representing a total of 585 species belonging to 108 genera and 23 families. Maximum species richness is recorded in the ANI (523 species of 95 genera belonging to 23 families), followed by the GoMBR (169 species belonging to 46 genera and 16 families), the LI (165 species from 54 genera and 17 families), and GoK (76 species of 30 genera and 12 families). Apart from these reefs, we also enlisted scleractinian fauna from other small reefs across the West coast of India, namely the Malvan Marine Sanctuary, Angria bank, Grande Island, and Netrani Island.

[**Keywords:** Biodiversity, Conservation, Coral reef, India, Taxonomy]

### Introduction

Coral reefs are incredibly diverse, valuable ecosystems and millions of population rely on the coral reefs for their livelihood and food security<sup>1</sup>. Nevertheless, coral reefs are facing a bleak future worldwide due to unprecedented climate change and rapid coastal development<sup>1-3</sup>. In Indian water, coral reefs are distributed along the East coast (Bay of Bengal) and the West coast (Arabian Sea) (Fig. 1). Being less than one percent, i.e., 2383.87 sq. km of the total reef formation of the world<sup>4,5</sup>, coral reefs in the Indian water are highly crucial in respect of ecosystem service and economy<sup>6</sup>. However, most of the Indian reefs have impacted by the ongoing climate change-induced elevated Sea Surface Temperature (SST) stress for the last three decades. Thermal stress has caused severe mass bleaching events and coral mortality in most of the coral reefs in India<sup>6-7</sup>, and severely degraded, significantly reduced species richness, and structural reef complexity in some of the Indian reefs<sup>5</sup>.

Taxonomical study on coral in India is dated back to 1847 by Rink from the Nicobar Islands<sup>5</sup>. After a prolonged gap, Pillai<sup>8</sup> conducted an extensive study on the coral fauna of the Gulf of Mannar and the

Lakshadweep. He listed a total of 125 species of corals of 34 genera and one subgenus<sup>8</sup>. In a series of publications, Pillai had documented species richness and coral community structure in the Gulf of Mannar, the Lakshadweep Islands and the Andaman and Nicobar Islands<sup>8-22</sup>. A detailed study on the coral diversity by Pillai<sup>8</sup> included 155 species of hard corals representing 50 genera and 44 families and 135 species of non-reef building corals belonging to 59 genera and 21 families from the ANI. The same study also reported the occurrence of 78 species of corals belonging to 31 genera from the Lakshadweep, 94 species from 37 genera in the Southeast coast of India and 37 species belonging to 24 genera from the GoK. After the pioneering work of Pillai<sup>8</sup>, the Zoological Survey of India (ZSI) has documented the diversity and distribution of corals in different coral reefs in Indian water, especially from the ANI. The effort of ZSI has yielded several new records of scleractinians from Indian water. Venkataraman *et al.*<sup>5</sup> documented 208 species of scleractinians belonging to 60 genera and 15 families from India, of which 177 species were from ANI, 91 species from LI, 82 species from GoMBR, and 36 species were from GoK. Subsequently, Turner *et al.*<sup>23</sup> reported 234 species of

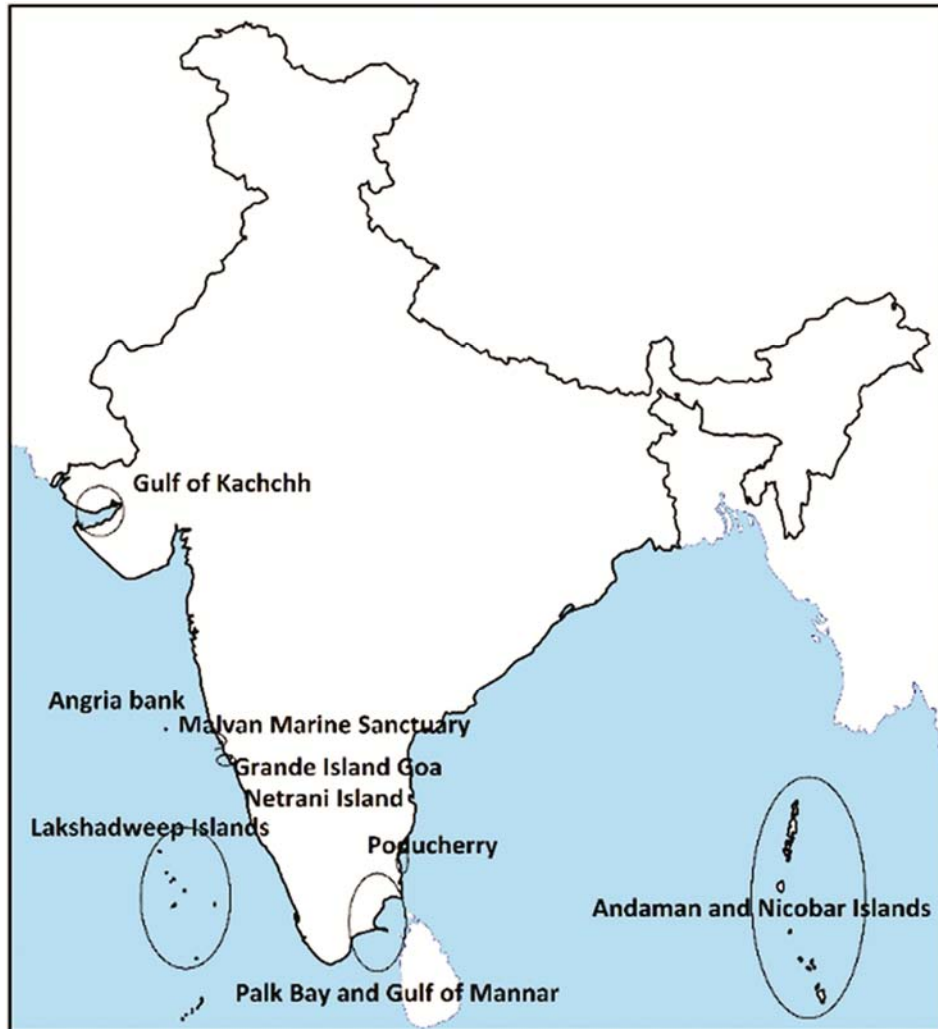


Fig. 1 — Distribution of major coral reefs in Indian water

scleractinian coral from the Andaman and Nicobar Islands with several new reports for the first time from the ANI as well as from India. A large number of coral species have been described from Indian coral reefs since the last two decades due to considerable effort by different institutions in India.

Coral taxonomy research in India is so far mostly based on morphological identification or the underwater observation. This problem further aggravates as the coral collection is legally restricted in India, hence, researchers mostly need to rely on field identification. Coral identification solely based on morphological observation and underwater monitoring comes with a certain amount of uncertainties, as corals exhibit phenotypic plasticity, intraspecific variation in appearance and skeletal characteristics across the habitat and geographic ranges<sup>24-25</sup>. Hence, identification of coral species

based on underwater observation and underwater photographs often leads to erroneous identification. Unfortunately, those misidentifications have been carried forward in subsequent publications. Therefore, in the present study, reviewed the previous occurrence reports of scleractinian corals in the Indian reefs and presented an updated checklist. Additionally, we compiled an annotated list of species that were erroneously reported by the different previous studies. Present study also examined the reef-wise species distribution to determine the species composition in each reef.

## Materials and Methods

### Methodology

The present article presents an updated checklist of the scleractinian fauna in Indian coral reefs. The species checklist is compiled based on the extensive

literature review of scientific reports, books, journal articles, and thesis those reported scleractinian diversity from Indian reefs. For this, different online databases, including Web of Science, Google Scholar, digital archives of Zoological Survey of India (ZSI), and Central Marine Fisheries Research Institute (CMFRI) were used. The taxonomic nomenclature presented in the *World List of Scleractinia*, (accessed through the World Register of Marine Species database <http://www.marinespecies.org><sup>24</sup>), was used to confirm the validity of the reported species name, to check the present taxonomic position, and to remove the synonymous/duplicate entries. The distribution range of the reported species was validated using the website *Corals of the World* (accessed through <http://coralsoftheworld.org><sup>25</sup>). Further, the study explored the unique and common species across the major Indian coral reefs by using Venny 2.1<sup>(ref. 26)</sup>.

## Results

The present check list consists of a total of 585 species belonging to 108 genera and 23 families of scleractinian fauna. Maximum species diversity is recorded in the ANI with 523 species belonging to 95 genera and 23 families, followed by GoMBR with 169 species of 46 genera and 16 families, LI with 165 species of 54 genera and 17 families, and GoK with 76 species of 30 genera and 11 families.

Acroporids contributed the most of species assemblage by 184 species belonging to six genera. Then, Merulinidae contributed with 100 species of 19 genera in overall species assemblage in Indian reefs. Poritidae consist of 52 species of four genera, and Fungiidae contributed by 42 species belonging to 15 genera. The dominant contributing genera are *Acropora* (104 species), *Montipora* (54 species), *Porites* (30 species), *Dipsastrea* (20 species), *Goniopora* (20 species), *Favites* (18 species), *Lobophyllia* (16 species) and *Pavona* (16 species). Detailed species list provided in Table S1 (please see the online version of the article).

From the coral occurrence reports in the GoK, we found that the Merulinidae is the most common family (25 species of eight genera), followed by Acroporidae (13 species of two genera). Poritidae and Dendrophyllidae represented by ten and nine species, respectively belonging to three genera. In the Lakshadweep Islands, Acroporidae (51 species of five genera), Merulinidae (34 species of 14 genera), and

Poritidae (17 species of two genera) form the major species assemblage. At the genera level, *Acropora* contributes 36 species, followed by *Porites* (14 species) and *Montipora* (nine species). In the GoMBR, Acroporidae contributed 58 species belonging to three genera. Merulinidae is the next dominating family with 45 species of 14 genera, followed by Poritidae with 19 species of four genera. *Acropora* is the most commonly occurring genus with 33 species, followed by *Montipora* with 23 species. Acroporids formed the dominant species assemblage in the ANI, consisting of a total of 164 species belonging to six genera. Merulinids contributed with 100 species distributed between 19 genera. Fungiidae family is represented by 42 species belonging to 15 genera. Lobophyllidae was the next dominant family, with 32 species and nine genera. Dendrophyllidae represented by 28 species belonging to nine genera. At the genera level, *Acropora* is the most dominating genus with 94 species, followed by *Montipora* (46), *Porites* (26), and *Dipsastrea* with 20 species, respectively.

Among the Indian reefs, ANI harbours 298 unique species (52.6 %) of all the reported species, which are not found in other reefs. Whereas, the GoMBR serves as a home for 28 (5 %) unique scleractinian species. Similarly, LI reefs have seven (1.2 %) unique species. Whereas, GoK harbours one (0.2 %) unique species, namely *Acanthastrea simplex*. The current investigation found that 36 common scleractinian species (6.4 % of the reported species) are present in all the four major reef regions (Fig. 2). Names of these species are presented in Table S1 with \*mark (please see the online version of the article).

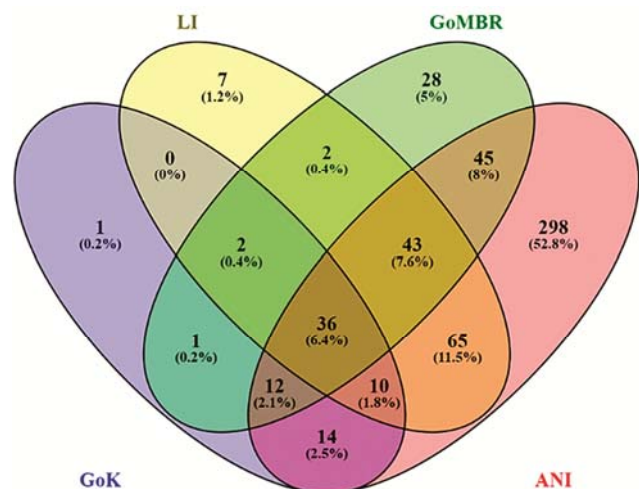


Fig. 2 — Comparative analysis of occurrence similarity and uniqueness of reported coral species across the major Indian reefs

## Discussion

Reefs in the Gulf of Kachchh (GoK) are located at North-Eastern part of the Arabian Sea and serve as home of some of the most northern reefs in the world<sup>27</sup>. Patel<sup>28,29</sup>, Pillai *et al.*<sup>20</sup>, and Pillai & Patel<sup>30</sup> presented the comprehensive account of coral diversity and distribution in the GoK. Further, Singh *et al.*<sup>31</sup> reported 42 species of hard-coral belonging to seven families and 24 genera. Satyanarayana & Ramakrishna<sup>32</sup> documented 49 species of corals (45 azooxanthellate and four zooxanthellate), with the first records of *Barabattoia amicornum*, *Favia lacuna*, *Favites flexuosa* and *Turbinaria frondens* from Indian water<sup>39</sup>. Raghuraman *et al.*<sup>33</sup> reported the occurrence of 49 species belonging to 27 genera and ten families. In a detailed study on reef ecology in GoK, Sreenath<sup>27</sup> noted the occurrence of 31 species of hard corals belonging to 20 genera and nine families and mentioned the new record of *Goniopora djiboutiensis*, *G. stokesi*, and *Hydnophora pilosa*. Further, Kumar *et al.*<sup>34</sup> presented an updated checklist showing the presence of 56 species belonging to 27 genera and ten families; however, they left out the new records described by Sreenath<sup>27</sup>. More recently, Marimuthu *et al.*<sup>35</sup> reported the presence of 53 species of hard coral based on available literature from GoK. However, the present checklist have compiled all the occurrence records and the number of the total hard coral fauna of GoK is represented by 76 species of 30 genera and 12 families, which is comparatively higher than earlier checklists. However, the presence of dead and fossilized colonies of *Acropora* was reported in the GoK, report of live *Acropora* colonies needs to be confirmed<sup>27,36</sup>.

In the South-Western part of India, Lakshadweep reef archipelago is located 200-400 km away from the Indian mainland and is formed by a series of coral atolls. Pillai & Jasmine<sup>37</sup> reported 104 species of scleractinians, of which 26 species were new record to the Lakshadweep. Suresh<sup>38</sup> recorded 105 species of scleractinian fauna, with a new record of 22 species and four genera (*Herpolitha*, *Leptoseris*, *Oulophyllia*, and *Pachiseris*). Caeiro<sup>39</sup> studied coral fauna of Lakshadweep Islands and reported the occurrence of 96 species of corals belonging to 34 genera and listed 28 new records for Lakshadweep., Jeyabaskaran<sup>40</sup> reported an additional occurrence of 20 species under 13 genera from this region. Additionally, Raghuraman *et al.*<sup>33</sup> recorded presences of 104 species (37 genera and 13 families) from this region.

Coral reefs in the GoMBR region are the Southern-most reefs of India. The GoMBR is featured by the presence of diverse types of reef forms such as fringing, shore platform, patch, and coral pinnacles. Pillai<sup>41</sup> described 94 species belonging to 37 genera from the GoMBR. Patterson *et al.*<sup>42,43</sup> provided a detailed account of the coral diversity and reported the presence of 117 hard coral species. Furthermore, Raghuraman *et al.*<sup>33</sup> enumerated 117 species from 40 genera and 14 families from this region. Additionally, Venkataraman & Rajan<sup>44</sup> reported the occurrence of 34 species from this region with 16 new distribution records, which is lower than the earlier finding of 63 species by Pillai<sup>45</sup>. In a recent study by Krishnan *et al.*<sup>46</sup> has identified 51 species from the GoMBR with 17 new distribution records from this region.

Andaman and Nicobar Islands (ANI) on the East coast of India are known for the remarkable coral faunal diversity<sup>33</sup>. However, most of the studies in the ANI are focused to the Mahatma Gandhi Marine National Park and in few other Islands. In contrast, several islands (there are 572 Islands in ANI) remain mostly unexplored so far<sup>47</sup>. Scheer & Pillai<sup>48</sup> and Pillai<sup>18-19,21-22</sup> documented the diversity and distribution of corals of ANI. Detailed taxonomic studies of coral reef in the ANI were conducted by the Zoological Survey of India (ZSI), Port Blair. Turner *et al.*<sup>23</sup> recorded a total of 198 species of scleractinian coral from different Islands, of which 111 were new records to India<sup>54</sup>. Additionally, Ramakrishna *et al.*<sup>47</sup> described 419 species of corals from ANI with a new occurrence record of 85 species of scleractinia. After that, another attempt to compile a checklist of corals from the major reefs of India was made by Raghuraman *et al.*<sup>33</sup> who reported 478 species under 89 genera and 19 families, of which 424 species (86 genera and 19 families) were from ANI. Subsequently, Mondal *et al.*<sup>46</sup> also presented an account of 173 species (48 genera and 14 families) from the Great Nicobar Island.

Extensive exploratory surveys and comprehensive taxonomic studies have helped to unveil the scleractinian diversity in the ANI region<sup>49-60,89-102</sup>. These studies have yielded in the discovery of novel species like *Favites monticularis* Mondal, Raghunathan, and Venkataraman, 2013<sup>50</sup>. Mondal *et al.*<sup>51</sup> reported the occurrence of a total of 628 species of hard corals from Indian reefs and 588 species from ANI. Although most of the coral species representing Indian reefs belong to the widespread

Indo-pacific species group, however, a few have been reported as endemic to Indian water<sup>5</sup>, viz. *Montipora jonesi* Pillai 1969; *Montipora manauliensis* Pillai 1969; *Porites exserta* Pillai 1969; *Porites minicoiensis* Pillai, 1969; *Porites mannarensis* Pillai 1969; *Alveopora superficialis* Pillai & Scheer, 1976; *Favites monticularis* Mondal, Raghunathan & Venkataraman 2013; and *Ctenactis triangularis* Mondal & Raghunathan 2013. Reefs in the Andaman and Nicobar Islands are biologically more diverse than other Indian reefs due to their geographic proximity and connectivity to the Indo-Pacific coral triangle<sup>5</sup>.

Furthermore, in some cases, a few species reported in Indian water are based on erroneous identification. For example, the occurrence report of the Caribbean species *Porites porites* from Andaman<sup>33</sup>, wherein the photographs in the same description resemble *Heliopora* sp.; and an Octocoral species (personal communication with Dr. Douglas Fenner). Additionally, some of the species reported from the Indian coral reefs, are found to be endemic to the Atlantic Ocean, or in the Caribbean and in other geographical areas. Such as *Halomitra clavator* (Höeksema, 1989) is native to Indonesia, Philippines, Malaysia, and Papua New Guinea, but is reported from the ANI<sup>52</sup>. Similarly, *Diploria clivosa* (Ellis & Solander, 1786) is reported from the GoMBR<sup>46</sup>, is a Caribbean species. Likewise, *Mussismilia braziliensis* (Verrill, 1868) is endemic to Brazilian water but reported from the Andaman<sup>53</sup>. Similarly, *Cantharellus noumeae* Hoeksema and Best, 1984, erroneously reported in Andaman<sup>47</sup>, which is an endemic species to New Caledonia and does not occur elsewhere. Furthermore, several species were misreported from the ANI by different authors, are generally native to the Caribbean and the Atlantic Ocean, for instances, *Mycetophyllia danaana* Milne Edwards & Haime, 1849<sup>33</sup>, *Pseudodiploria strigosa* (Dana, 1846)<sup>33</sup>, *Agaricia fragilis* Dana, 1848<sup>33</sup>, *Favia fragum* (Esper, 1797)<sup>54</sup>, *Mussa angulosa* (Pallas 1766)<sup>55</sup>, *Solenastrea bournoni* Milne Edwards & Haime, 1849<sup>33,56</sup>, *Siderastrea radians* (Pallas, 1766)<sup>33</sup>, *Siderastrea sidereal* (Ellis & Solander, 1786)<sup>59</sup>, *Leptoseris cucullata* (Ellis & Solander, 1786)<sup>33</sup>, *Porites porites* (Pallas, 1766)<sup>56,60</sup>, *Mycetophyllia lamarckiana* Milne Edwards & Haime, 1848<sup>59</sup>, and *Leptoseris cucullata* (Ellis & Solander, 1786)<sup>92</sup>. Therefore, these species records are excluded from the present checklist. The occurrences of *Montastrea annularis* (Ellis &

Solander, 1786) were reported from the ANI Islands<sup>59</sup> and the GoMBR<sup>47</sup>, which is previous combination of *Orbicella annularis* (Ellis & Solander, 1786) and is endemic to Atlantic water<sup>24</sup>.

The present study also found that some species are reported in different synonymy claiming them as new occurrences from Indian water. For example, *Acropora cytherea* (Dana, 1846) was reported from the Lakshadweep, and in ANI with different synonyms. Pillai<sup>15</sup> reported this species from Lakshadweep as *Acropora efflorescens* (Dana, 1846) and *Acropora reticulata* (Brook, 1892). The same species was recorded as *Acropora armata* (Brook, 1892) and *Acropora corymbosa* (Lamarck, 1816) by Reddiah<sup>55</sup> from the ANI. Further, Tikadar *et al.*<sup>74</sup> reported the same species from ANI as *Acropora efflorescens* (Dana, 1846). To mitigate such ambiguity, the WoRMS database<sup>24</sup> was used to identify the synonymous entries and enlist the present valid species names. Additionally, we have provided a list of 203 species of scleractinian along with detailed remarks, those were reported in earlier literature, but have excluded in the present checklist (Appendix I, please see the online version of the article).

Apart from the four main coral reefs of India, the occurrence of patch reefs has been reported from several locations on the Central West coast of India, where occurrence of corals can be found from intertidal rock pools to subtidal region<sup>61-62</sup>. These small reefs are characterized by rocky substratum, high turbidity due to land-based runoff, and monsoonal dilution of seawater salinity<sup>61</sup>. Information on the detailed biodiversity of these reefs is still sparse. Previous studies have reported occurrence of hard corals from Ratnagiri, Redi, South of Bombay, Malvan Marine Sanctuary (MMS)<sup>61-64</sup>, Grande Islands in Goa coast<sup>65-66</sup>, Netrani Island in Karwar coast<sup>67</sup>, and from Angria bank off Malvan coast<sup>68</sup>. The presence of hard coral species is also reported from Quilon in the Kerala coast to Enayem in Tamilnadu<sup>69</sup>. Pillai & Jasmine<sup>70</sup> reported the occurrence of 13 species of hard corals from six genera and 16 species of ahermatypic corals belonging to 11 genera from a depth of 40 to 100 meters in the Southwest coast (Kerala, Tamilnadu) of India. In MMS, reported species includes *Porites lichen* Dana, 1846; *Porites lutea* (Quoy & Gaimard, 1833); *Goniopora pedunculata* Quoy & Gaimard, 1833; *Goniopora* sp.; *Coscinaraea monile* (Forskål, 1775); *Pseudosiderastrea tayami* Yabe & Sugiyama, 1935;

*Siderastrea savignyana* Milne Edwards & Haime, 1850; *Cyphastrea serailia* (Forskål, 1775); *Turbinaria mesenterina* (Lamarck, 1816); *Synarea* sp.; *Montastrea* sp.; *Leptastrea* sp.; *Pavona* sp.; *Goniastrea retiformis* (Lamarck, 1816); *Favites halicora* (Ehrenberg, 1834); *Favites* sp.; *Leptastrea purpurea* (Dana, 1846); *Tubastraea coccinea* Lesson, 1829; *Polycyathus verrilli* Duncan, 1889; and *Pavona bipartita* Nemenzo, 1979<sup>(refs. 62-64)</sup>.

In the Grande Islands, presence of *Porites* sp., *Goniopora* sp., *Coscinaraea* sp., *Pocillopora* sp., *Siderastrea* sp., *Turbinaria* sp., *Montastrea* sp., *Leptastrea* sp., *Goniastrea* sp., *Favites* sp., *Favia* sp., *Plesiastrea* sp., *Balanophyllia cumingii* Milne Edwards & Haime, 1848, *Dendrophyllia indica* Pillai, 1969, and *Paracyathus profundus* Duncan, 1889 were confirmed by different studies<sup>65-66</sup>.

Zacharia *et al.*<sup>67</sup> reported occurrence of *Porites* sp., *Goniopora* sp., *Coscinaraea* sp., *Coscinaraea monile* (Forskål, 1775), *Pocillopora verrucosa* (Ellis & Solander, 1786), *Pocillopora* sp., *Turbinaria* sp., *Symphyllia* sp., *Leptastrea* sp., *Dendrophyllia* sp., *Goniastrea retiformis* (Lamarck, 1816), *Goniastrea pectinate* (Ehrenberg, 1834), *Favia favus* (Forskål, 1775), and *Plesiastrea versipora* (Lamarck, 1816) in the Netrani Island, Karnataka coast.

Ingole<sup>68</sup> revealed the species assemblage in the Angria bank, which included *Acanthastrea* sp., *Sclerophyllia* sp., *Lobophyllia corymbosa* (Forskål, 1775), *Dipsastraea* sp., *Dipsastraea speciosa* (Dana, 1846), *Echinophyllia* sp., *Echinophyllia pectinata* Veron, 2000, *Mycedium* sp., *Scolymia* sp., *Fungia* sp., *Ctenactis* sp., *Echinopora* sp., *Galaxea* sp., *Favites* sp., *Goniastrea* sp., *Paragoniastrea* sp., *Leptastrea* sp., *Psammodora* sp., *Plesiastrea versipora* (Lamarck, 1816), *Astreopora* sp., *Euphyllia ancora* Veron & Pichon, 1980, *Coelastrea* sp., *Pachyseris speciosa* Dana, 1846, *Platygyra* sp., *Leptoseris* sp., *Pocillopora* sp., *Porites lobata* Dana, 1846, *Porites solida* Forskål, 1775, *Goniopora* sp., *Symphyllia* sp., *Turbinaria mesenterina* (Lamarck, 1816), and *Turbinaria peltata* Esper, 1794.

More recently, Laxmilata *et al.*<sup>71</sup> documented mesophotic coral reef-associated biota from Puducherry, including 12 species belonging to ten genera and seven families, viz. *Leptoseris explanata* Yabe & Sugiyama, 1941; *Pavona minuta* Wells, 1954; *Pavona maldivensis* (Gardiner, 1905); *Tubastraea micranthus* (Cairns and Zibrowius, 1997); *Tubastraea coccinea* Lesson, 1829; *Euphyllia ancora*

Veron and Pichon, 1980; *Hydnophora rigida* (Dana, 1846); *Goniastrea pectinata* (Ehrenberg, 1834); *Dipsastraea favus* (Forskål, 1775); *Psammodora haimeana* Milne Edwards & Haime, 1851; *Pachyseris speciosa* (Dana, 1846); and *Cycloseris* sp.

## Conclusion

The authors admit that some of the entries in the present checklist are based on the list of coral species reported in publications, which are lacking taxonomic details and photographs; hence, we could not verify these reports. Inclusion of synonyms and endemic species of the Atlantic Ocean and elsewhere, point out the taxonomic ambiguity in some of the previous occurrence reports from Indian water. Therefore the present study highlights an urgent need of revision of the voucher specimen and application of advanced molecular tools for further confirmation. Additionally, a detailed taxonomic study with a more comprehensive geographical range, preferably comparison of the coral skeleton with the other holotype samples, is essential to delineate the Indian scleractinian fauna truly. Hence, a dedicated taxonomical research program with a combination of classical morphological identification keys and incorporation of molecular phylogenetic techniques, along with inter-institute or international collaboration, would be helpful to unveil new coral records and rectification of earlier erroneous reports, which will be helpful to underline conservation policies.

## Supplementary Data

Supplementary data associated with this article is available in the electronic form at [http://nopr.niscair.res.in/jinfo/ijms/IJMS\\_49\(10\)1651-1660\\_SupplData.pdf](http://nopr.niscair.res.in/jinfo/ijms/IJMS_49(10)1651-1660_SupplData.pdf)

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## Conflict of Interest

Authors declare no competing or conflict of interest.

### Author Contributions

KD: Conceptualization; Investigation, Formal analysis, Software; Writing - original draft, Writing - review & editing; VK: Writing - original draft, Writing - review & editing; BI: Conceptualization; Funding acquisition, Resources; Supervision, Writing - review & editing

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