



Community structure and spatial patterns in hard coral diversity of Agatti Island, Lakshadweep, India

K. R. SREENATH¹, S. JASMINE², RANI MARY GEORGE², L. RANJITH³
K. MOHAMED KOYA¹ AND J. KINGSLEY²

¹Regional Centre of ICAR-Central Marine Fisheries Research Institute, Matsya Bhavan, Veraval - 362 269 Gujarat, India

²Research Centre of ICAR-Central Marine Fisheries Research Institute, Vizhinjam, Thiruvananthapuram - 692 521 Kerala, India

³Research Centre of ICAR-Central Marine Fisheries Research Institute, South Beach Road, Thoothukudi Tamil Nadu - 628 001, India
e-mail: lecologiste@gmail.com

ABSTRACT

Lakshadweep Island cluster is the single atoll reef formation in India, which is reported to be facing climate abnormalities since the past few decades. Scleractinian corals form the structural framework of any coral reefs and are very important in the existence of atoll reef systems. In the present study an attempt was made to investigate the hard coral diversity, live/dead coral cover, as well as health status of reef system surrounding Agatti Island in the Lakshadweep Sea, adopting the Line Intercept Transect (LIT) method. Seventy one species were recorded from the island, of which 37 were new to the reef. *Acropora formosa* (Dana, 1846) with a total cover of 18.3% showed maximum abundance followed by *Porites lutea* (14.8%) and *Porites lichen* (10.7%). Percentage live coral cover was recorded as fair (48.6%) and coral mortality index (0.29) indicated that the reef is in the borderline between healthy and sick state. Proper management measures should be adopted to increase the coral cover of the reef area and to prevent further destruction of the reef.

Introduction

Coral reefs are ancient and extremely complex communities functioning as a single unit. Despite the fact that coral reefs form only 0.2% percentage of marine environment, these are home to one-third of known marine species (Reaka-Kudla, 1997; 2001). The economic value of resources and services derived from them is estimated at \$375 billion per year (Costanza *et al.*, 1997) which directly or indirectly provides considerable economic benefits to many of the countries. India's coral reef system comprises four major components *viz.*, the Andaman and Nicobar Islands, the Gulf of Kachchh, Lakshadweep Islands and the Palk Bay and Gulf of Mannar Biosphere Reserve. Lakshadweep Islands, a group of scattered coral reef islands in the Arabian Sea are the only atoll type of reefs in the territory of India (Jones, 1986). Raghuraman (2012) compiled the scleractinian diversity of India and made a list of 424 species belonging to 86 genera and 19 families.

The Lakshadweep group of islands, off the west coast of India, constitutes one of the smallest Union Territory (UT), with Kavaratti as its capital. The UT comprises 10 inhabited islands, 17 uninhabited islands, one with

attached islet, 4 newly formed islets and 5 submerged reefs. The islands are located between 230 to 400 km west of Kerala coast, between latitudes 8°00' and 12°30' N and longitudes 71°00' and 74°00' E. Most of these islands are aligned in a roughly north-west direction and have a wider lagoon in the western side as compared to the eastern side of the islands with exception in case of Androth Island (James, 1989). Total area of all these islands is 32 sq. km and the inhabited islands vary in size from 0.1 sq km to 4.8 sq km (Department of Planning and Statistics, 2002).

Agatti Island is the western most island in the Indian UT of Lakshadweep, located at 10° 81' to 87° N and 72° 15' to 21' E. The island has an estimated area of 2.7 km² and is surrounded by 12 km² of lagoon and 14.4 km² of reef flat (Bahuguna and Nayak, 1994). As many other islands of the region, Agatti is also aligned north-south (north-east to south-west direction) and has a deeper and wider lagoon in the western region. Kalpitti, a small islet lies south of Agatti within the periphery of the lagoon.

Earlier works on the coral fauna of Lakshadweep initiated by Gardiner (1904, 1905) and later by Nagabhushanam and Rao (1972) were mainly on the fauna of Minicoy Island. Pillai (1976; 1983a; 1986)

extensively studied the scleractinian diversity over a range of Lakshadweep islands, which led to the identification of 103 species of hard corals belonging to 37 genera (Pillai and Jasmine, 1989). Further, Pillai (1996) published a detailed status report on the corals, which remains to be the basic document on the coral reefs of India. After a bleaching event during 1998 which reduced the coral coverage by 81% (Arthur, 2000), post-bleaching recovery was found to be significant in western reefs of Agatti than in the eastern side (Arthur *et al.*, 2005; 2006) due to differences in settlement pattern and substrate stability (Tamelander and Rajasuriya, 2008). The last report of bleaching was in the year 2010 (Kumar and Subramanian, 2012). An increase in seagrass cover in some of the Lakshadweep islands is attributed to an increase in eutrophication due to anthropogenic pressure (Bahuguna *et al.*, 2013). Other than fishing, islanders exploit corals which they use for building houses, roads and for other constructions (Wells and Sheppard, 1988). Despite the regulations imposed by the Ministry of Environment and Forests (MoEF), Govt. of India, the collection of corals from the shores are being undertaken which may weaken the beachfront (Pillai, 1996). Dredging activities in lagoons have resulted in the removal of reef fronts in some areas to allow the passage of boats, which permanently affected current flow in and out of the lagoon (Pillai, 1983a; 1996).

Agatti Island together with its islet, Kalpitti has a vast lagoon of 4 to 5 m deep in the west side and is mostly sandy with mounts and boulders formed by *Porites* spp. Main entrance to the lagoon with passage for mechanised fishing vessels is located towards the northern point. Lagoon is being occasionally dredged from the western entrance, Baliya Alivui for facilitating passage of large cargo vessels. Dredging and wave action carries dead coral fragments and coral rubbles towards the northern side of the lagoon. Studies on demography, socio-economic status of the islanders, use of the coral reef resources and fishing methods have been conducted in the Agatti Island and its territories (Hoon *et al.*, 2002; Hoon 2003; Hoon and Tamelander 2005; James, 2011). Being a fast developing island, the increased interference on the ecosystem is reflected on the present status of the reefs of Agatti. The present study assessed the health of this reef by deriving percentage of live and dead coral cover, diversity indices, as well as the relative abundance of various coral species, aiming at formulation of viable strategies for the protection, conservation and sustainable use of the precious coral wealth.

Materials and methods

Survey and sampling was carried out during March 2013 by SCUBA diving and snorkeling. Line Intercept Transect (LIT) method (English *et al.*, 1997) was adopted

to describe coral community and composition. A total of 10 transect lengths of 30 m each (3 each in the northern and southern reef crests, 2 in the lagoon and 2 in the south-east reef crest) (Table 1) with three replicates set apart by 5 m were placed parallel to the reef break at 1 to 3 m deep areas of reef crest (Fig. 1). The intercepts of all underlying coral species, dead corals, rock, sand, rubble, algae and others (holothurians, anemones, giant clams and other molluscs) were recorded. Digital photographs and videographs of corals were taken using Canon D10 and Sony Cybershot RX100 respectively. Identification of corals was made *in situ* following Pillai (1967a, b, c; 1973; 1986), Veron (1986; 2000), Wallace (1999) and Venkataraman *et al.* (2003). For statistical analysis of the data, Primer software 6 package was used (Carr, 1996).

Table 1. LIT stations and their respective geographic coordinates

Station	Coordinates
S1	Lat 10.874413°, Long 72.191788°
S2	Lat 10.868285°, Long 72.179571°
S3	Lat 10.879234°, Long 72.198802°
S4	Lat 10.825292°, Long 72.159697°
S5	Lat 10.838150°, Long 72.156683°
S6	Lat 10.835000°, Long 72.180980°
S7	Lat 10.823496°, Long 72.170587°
S8	Lat 10.848083°, Long 72.159129°
S9	Lat 10.811572°, Long 72.172460°
S10	Lat 10.821111°, Long 72.177599°

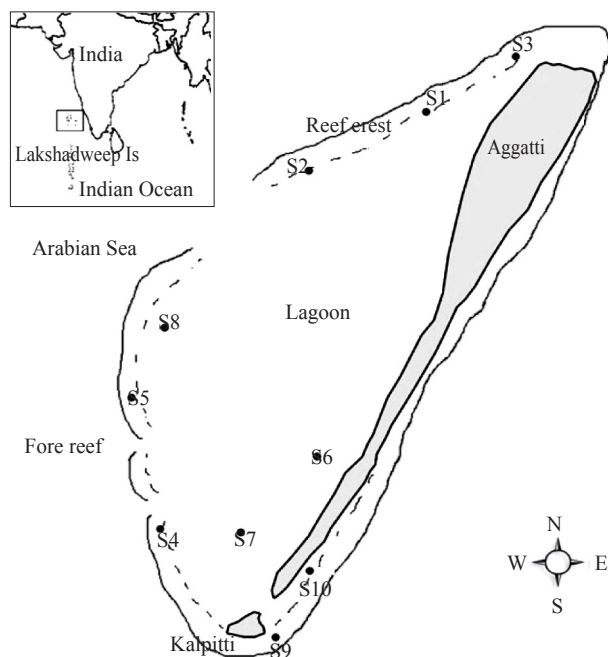


Fig. 1. Map showing positions of the LIT stations covered under the study in Agatti atoll. Stations 1 to 10 are shown in the map as S1 to S10.

Community analysis

The relative abundance (RA), which is an index of commonness or rarity, of each coral species was calculated as (Rilov and Benayahu, 1998):

$$\text{Relative abundance (RA)} = \frac{P_i}{P_{\text{total}}} \times 100$$

where, P_i = pooled living coverage of the i^{th} species from all transects at a given site and P_{total} = pooled total living coverage of all species in all transects at a given site.

Resulting values were transformed into abundance categories (%) viz., not recorded (RA=0), rare (0<RA<0.1), uncommon (RA=0.1-1), common (RA=1-10), abundant (RA=10-20) and dominant (RA>20).

Univariate analysis

Based on coral coverage of each individual species on each transect, species diversity indices, Shannon-Weiner diversity index (H') and Gini-Simpson index (1-Lambda) as well as the evenness index, Pielou's index were calculated using natural logarithm values (Gini, 1912; Shannon and Weiner, 1949; Simpson, 1949; Margalef, 1958; Pielou, 1977).

Graphical descriptors

K-dominance curves (Lambshead *et al.*, 1983), a graphical biodiversity descriptor, were constructed for finding out the diversity profile of different sampling sites. The starting point of curve and its inclination is indicative of the diversity of the site *i.e.*, more elevated curves which starts high have lower diversity and *vice versa*.

Multivariate analysis

Data was first transformed [$\ln(x+1)$] to reduce the influence of dominant taxa. A resemblance matrix for

different stations was constructed using the similarity coefficient of Bray and Curtis (1957). Similarity pattern, *i.e.*, similarity between each station and their distances were visualised in a two-dimensional plot using non-metric multidimensional scaling (MDS). The contribution of species to variations between the clusters observed in the ordination analysis was examined using the SIMPER (Similarity Percentage Analysis) procedure (Clarke, 1993). Species falling above the 50% similarity threshold were considered to be those most important in determining community structure.

Coral mortality index (Gomez *et al.*, 1994) was adopted to analyse the health of the reefs. As opposed to measure of diversity or percent coral cover, MI is a multivariate index that is a simple ratio between proportions of dead coral cover to both live and dead coral cover.

$$\text{Mortality index (MI)} = \frac{\text{Dead coral cover}}{\text{Live coral} + \text{Dead coral cover}}$$

If $MI > 0.33$, the mortality index is considered to be high and the reef is classified as sick.

Results and discussion

Reef around Agatti atoll showed an average live coral cover of 48.6% (Fig. 2) and the average dead coral coverage recorded was 21.6%, most of which were covered with algae. Bleached corals were observed to be minimum during the present survey. Similar survey undertaken during 2005 reported a coral coverage of 58% and dead coral cover of 24.1%, from the mean values of three transects made around the Agatti atoll (George, 2008). Fewer occurrences of bleaching and algal cover

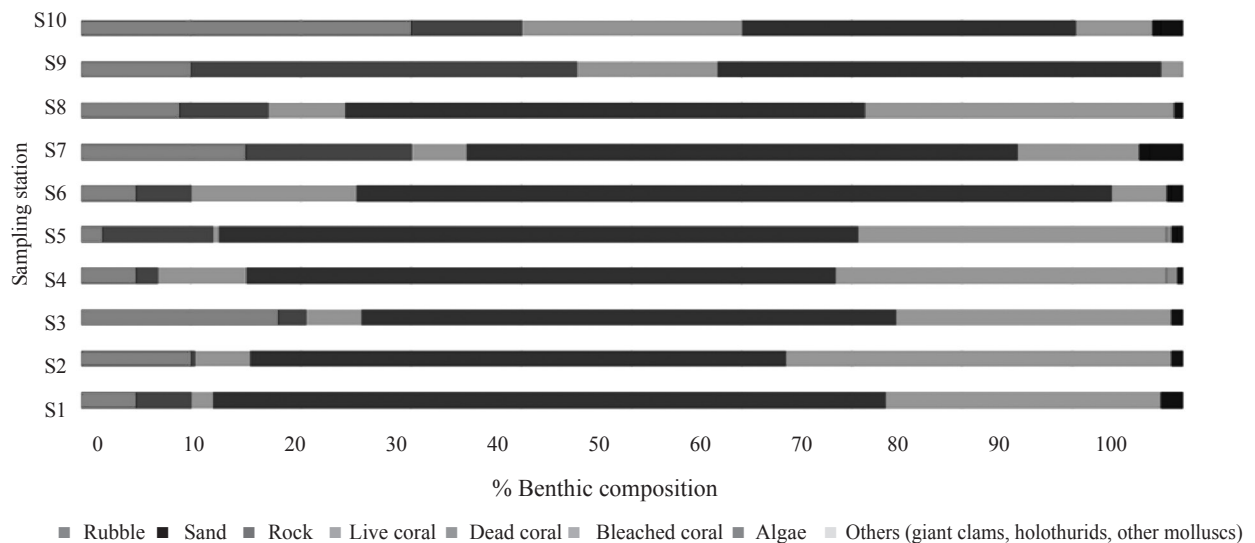


Fig. 2. Overall percentage benthic composition at different sampling sites

on almost all dead corals observed during the present study, can be indicative of a past catastrophe, which may be attributed to the bleaching event in 1998 or tsunami in 2004. During 1998 bleaching event Lakshadweep atolls lost between 43 and 87% of live coral cover (Wafar, 1999). Vivekanandan *et al.* (2008) reported coral bleaching across the coast of south Asian countries, particularly along the Indian coast along Gulf of Mannar and Lakshadweep, which experienced more or less same elevated sea surface temperature (SST). Loss of live coral cover is often associated with phase-shift from a coral dominated community structure to algae dominated ecosystem (Done 1992; McCook 1999). Survey under Lakshadweep Coral Reef Monitoring Network (LCRMN) initiated by Lakshadweep Administration observed encouraging recovery rate of 1.6% and live cover of 39.2% by 2007 after the bleaching event in 1998 (Raheem, 2012). Kumar and Balasubramanian (2012) reported 76.5% bleaching of hard corals in the Agatti lagoon during the pre-monsoon season of 2010.

Seventy one species of hard corals belonging to 28 genera and 13 families including two non-scleractinian species were recorded along the transects. Out of this, 37 species are new records from the Island (Table 2). Earlier works of Pillai and Jasmine (1989) reported 27 species belonging to 10 genera from Agatti Island. However, Suresh (1991) observed a total of 60 stony coral species belonging to 27 genera from Agatti Island following quadrant survey methodology. No single species were categorised as ‘dominant’ in the present study. *Acropora formosa* and *Porites lutea* belonged to the category ‘Abundant’ with the relative abundance values of 18.3 and 14.8 respectively (Table 2). Studies on the skeletal extension of *A. formosa* at Kavaratti atoll indicate that the environmental conditions of Lakshadweep waters are conducive for the growth of *A. formosa* (Suresh and Mathew, 1993). Relative abundance values of all other species were less than 10, making 20 of them as common, 37 as uncommon and 11 species as rare. *Acropora nobilis*, *Acropora valenciennesi*, *Astreopora ocellata*, *Echinopora lamellosa*, *Gardineroseris planulata*, *Hydnophora exesa*, *Leptastrea purpurea*, *Montastrea valenciennesi*, *Turbinaria mesenterina* and *Euphyllia* sp. were the scleractinians that showed rare occurrence in transects. *Heliopora coerulea* and *Millepora exesa* were the only non-scleractinian corals observed in the current study though Suresh (1991) recorded *Millepora platyphyllia* and *Tubipora musica* also from the island.

Margalef index, which gives weightage to the number of species than the number of individuals, shows that site S7 and S9 have less number of species. Shannon diversity index ranged from 2.25 (S7) to 3.23 (S6). Value

of Shannon index above 3 indicates that the structure of habitat is stable and balanced. Value of Simpson’s diversity index is near to one, which shows a high diversity in all the sites. High and even value of Pielou’s index shows that the individuals are distributed equally (Table 3). This index is similar for all the sites though S7 shows marginally high even distribution of species. With its low starting point and gentle slope, K-dominance curve confirmed high diversity at site S6 and least diversity at S7 (Fig. 4). S6 site was characterised with massive boulders of *Porites solida* upon which grows different species of the genus *Acropora*. This site is being specially looked after and the local divers of Agatti have installed fabrications of boulders with variety of Acroporids for tourism purpose. Similarly S7, a random site selected in the shallow southern half of the lagoon comprised mainly of rubbles, sand and dead coral fragments. SIMPER analysis showed that major species, which contributed to all sites surveyed, were *Acropora formosa* (19.5%) and *Porites lutea* (14.8%). Average similarity in species composition was 44.8% (Table 4). SIMPER analysis between different clusters *viz.*, north-south, lagoon and south-east showed that *Acropora palifera* discriminated northern reefs and *Goniastrea retiformes* discriminated southern reefs from others (Table 5). No common species was identified to represent the dissimilarity between other sites. Analysis between western and eastern side reefs showed *Acropora gemmifera*, *A. palifera* and *G. retiformis* as the major contributing species (Table 6) for the variation. Bray Curtis similarity as plotted in MDS plot showed clustering of data towards the northern sites and south-east sites with a similarity of 60% (Fig. 5).

Based on reef condition index (RCI) (Gomez and Alcala, 1979) values estimated, Agatti Island reefs fall under the category “fair”. Similar live coral coverage of 58% was reported earlier by George (2008). Average coral mortality index (MI) for the reef was 0.29, which shows that the health of the reef is in a better condition, though it is nearing the cut off value of 0.33 to fall under the category ‘sick’. Coremap (2001) questions the statistical relevance of coral mortality index and recommends using the coral cover as indicator of reef condition. Nevertheless, both the indices show that the reef is in a borderline state of health.

Atoll islands like Lakshadweep are formed by generations of corals built upon skeleton of their ancestors (Darwin, 1842). These coral reef ecosystems are vulnerable to any changes in their homeostasis due to both natural and anthropogenic reasons (Sorokin, 1992). Variables like temperature, irradiance, calcium carbonate saturation, turbidity, sedimentation, salinity, pH and nutrients influence the physiological processes of photosynthesis, calcification and hence the coral survival (Buddemeier *et al.*, 2004; Crabbe *et al.*, 2008; 2009).

Table 2. Relative abundance (RA) and status of species reported during various studies from Agatti Island

Species name	Species status recorded in different studies			RA (Present study)
	Pillai and Jasmine (1989)	Suresh (1991)	Present study	
Scleractinian corals				
<i>Acanthastrea echinata</i> (Dana, 1846)		R		
<i>Acropora abrotanoides</i> (Lamarck, 1816)		R	C	1.34
<i>Acropora aspera</i> (Dana, 1846)	P	R	C	1.1
<i>Acropora austere</i> (Dana, 1846)		C	U	0.88
<i>Acropora cervicornis</i> (Lamarck, 1816)			U	0.31
<i>Acropora corymbosa</i> (Lamarck, 1816)	P	R		
<i>Acropora cytherea</i> (Dana, 1846)			U	0.2
<i>Acropora divaricata</i> (Dana, 1846)			U	0.25
<i>Acropora echinata</i> (Dana, 1846)		R		
<i>Acropora formosa</i> (Dana, 1846) (Fig. 3a)	P	A	A	18.28
<i>Acropora gemmifera</i> (Brook, 1892)			C	2.55
<i>Acropora gracilis</i> (Dana, 1846)		C		
<i>Acropora hemprichi</i> (Ehrenberg, 1834)			U	0.75
<i>Acropora humilis</i> (Dana, 1846)		C	C	1.05
<i>Acropora hyacinthus</i> (Dana, 1846)	P	R	U	0.23
<i>Acropora intermedia</i> (Brook, 1891)	P			
<i>Acropora irregularis</i> (Brook, 1892)			U	0.32
<i>Acropora lamarcki</i> Veron, 2000			U	0.75
<i>Acropora longicyathus</i> (Milne Edwards, 1860)			C	1.2
<i>Acropora microphthalma</i> (Verrill, 1869)			C	1.07
<i>Acropora millepora</i> (Ehrenberg, 1834)			U	0.11
<i>Acropora monticulosa</i> (Bruggemann, 1879)		R		
<i>Acropora myriophthalma</i> (Verrill, 1869)		C		
<i>Acropora nasuta</i> (Dana, 1846)			R	0.02
<i>Acropora nobilis</i> (Dana, 1846)			U	0.53
<i>Acropora palifera</i> (Lamarck, 1816) (Fig. 3b)		C	C	7.4
<i>Acropora robusta</i> (Dana, 1846)			U	0.42
<i>Acropora tenuis</i> (Dana, 1846)			C	1.65
<i>Acropora teres</i> (Verrill, 1866)	P	R		
<i>Acropora valenciennesi</i> (Milne Edwards, 1860)		R	R	0.06
<i>Agaricia</i> sp.			U	0.66
<i>Astreopora listeria</i> Bernard, 1896			U	0.11
<i>Astreopora myriophthalma</i> (Lamarck, 1816)			U	0.22
<i>Astreopora ocellata</i> Bernard, 1896			R	0.05
<i>Cyphastrea serialia</i> (Forsk., 1775)	P	A	U	0.22
<i>Echinopora lamellose</i> (Esper, 1795)		R	R	0.02
<i>Euphyllia</i> sp.		R	U	0.1
<i>Favia fava</i> (Forsk., 1775)		R	U	0.42
<i>Favia pallida</i> (Dana, 1846)		R	U	0.27
<i>Favia speciosa</i> (Dana, 1846)		R	U	0.55
<i>Favia stelligera</i> (Dana, 1846)		R		
<i>Favia valenciennesi</i> (Milne Edwards and Haime, 1848)		R		
<i>Favites flexuosa</i> Dana, 1846		R		
<i>Favites halicora</i> (Ehrenberg, 1834)		R		
<i>Favites melicerum</i> (Ehrenberg, 1834)	P	R		
<i>Favites pentagona</i> (Esper, 1794)		R		
<i>Favites</i> sp.1			U	0.54
<i>Favites</i> sp.2			U	0.25
<i>Fungia danae</i> Milne Edwards and Haime, 1851)			U	0.21
<i>Fungia fungites</i> (Linnaeus, 1758) (Fig. 3c)	P	C	U	0.64
<i>Fungia repanda</i> Dana, 1846)			U	0.33
<i>Fungia scutaria</i> Lamarck, 1801)	P	A	U	0.17
<i>Galaxea astrea</i> (Lamarck, 1816)			U	0.42

Species name	Species status recorded in different studies			RA (Present study)
	Pillai and Jasmine (1989)	Suresh (1991)	Present study	
<i>Galaxea fascicularis</i> (Linnaeus, 1767) (Fig. 3d)		C	U	0.92
<i>Gardineroseris planulata</i> (Dana, 1846) (Fig. 3e)		R	R	0.05
<i>Goniastrea pectinata</i> (Ehrenberg, 1834)		C		
<i>Goniastrea retiformis</i> (Lamarck, 1816)		C	C	3.03
<i>Goniopora minor</i> Crossland		R	C	1.19
<i>Goniopora stokesi</i> Milne Edwards and Haime, 1851		R		
<i>Hydnophora exesa</i> (Pallas, 1766)		R	R	0.09
<i>Hydnophora microconos</i> (Lamarck, 1816)	P	C	U	0.11
<i>Leptastrea purpurea</i> (Dana, 1846) (Fig. 3f)		A	R	0.06
<i>Leptastrea transversa</i> Klunzinger, 1879		C	U	0.13
<i>Leptoria phrygia</i> (Ellis and Solander, 1786)		C	C	1.52
<i>Leptoseris</i> sp.			U	0.45
<i>Lobophyllia corymbosa</i> (Forsk., 1775)		R		
<i>Montastrea valenciennesi</i> (Milne Edwards and Haime, 1848)			R	0.04
<i>Montipora tuberculosa</i> (Lamarck, 1816)		C		
<i>Montipora</i> sp.			U	0.1
<i>Pavona maladivensis</i> (Gardiner, 1905)		R		
<i>Pavona minuta</i> Wells, 1954		R		
<i>Pavona varians</i> Verrill, 1864			U	0.4
<i>Platygyra daedelea</i> (Ellis and Solander, 1786)	P			
<i>Platygyra lamellina</i> (Ehrenberg, 1834)			C	2.7
<i>Platygyra sinensis</i> (Milne Edwards & Haime, 1849)	P	C		
<i>Platygyra</i> sp.			U	0.65
<i>Pocillopora damicornis</i> (Linnaeus, 1758)	P	A	C	2
<i>Pocillopora eydouxi</i> Milne Edwards, 1860)			C	2
<i>Pocillopora meandrina</i> Dana, 1846	P			
<i>Pocillopora verrucosa</i> (Ellis and Solander, 1786)		R	C	1.54
<i>Porites andrewsi</i> (Vaughan, 1918)	P			
<i>Porites annae</i> Crossland, 1952			U	0.8
<i>Porites australiensis</i> Vaughan, 1918			C	1.63
<i>Porites cylindrica</i> Dana, 1846		C	C	7
<i>Porites lichen</i> Dana, 1846			C	5.73
<i>Porites solida</i> (Forsk., 1775)	P	A	C	2.63
<i>Porites lutea</i> Milne Edwards, 1860	P	A	A	14.75
<i>Porites rus</i> (Forsk., 1775)		C		
<i>Psammacora contigua</i> (Esper, 1794)	P	A	C	1.45
<i>Psammacora digitata</i> Milne Edwards and Haime, 1851		R		
<i>Psammacora haimaenia</i> (Milne Edwards and Haime, 1851)	P		U	0.72
<i>Psammacora profundacella</i> Gardiner, 1898		R		
<i>Symphyllia nobilis</i> (Dana)		R		
<i>Symphyllia radians</i> Edwards and Haime, 1849		R	U	0.42
<i>Symphyllia recta</i> (Dana, 1846)			U	0.41
<i>Symphyllia</i> sp.			U	0.24
<i>Tubastrea aurea</i> (Quoy and Gaimard, 1833)		R		
<i>Turbinaria crater</i> (Pallas)	P			
<i>Turbinaria mesenterina</i> (Lamarck, 1816)	P	C	R	0.08
<i>Turbinaria stelullata</i> (Lamarck, 1816)		C		
<i>Turbinaria</i> sp.	P			
Non-scleractinian corals				
<i>Heliopora coerulea</i> (Pallas, 1766)		R	C	1.5
<i>Millepora exesa</i> (Forsk., 1775)	P		R	0.01
<i>Millepora platyphyllia</i> Hemprich and Ehrenberg, 1834		R		
<i>Tubipora musica</i> Linnaeus, 1758		R		

P: Present; A: Abundant, C: Common, U: Uncommon, R: Rare

Table 3. Biodiversity indices and coral mortality index estimated at different sites

Sites	d	J'	H' (ln)	1-Lambda'	MI
S1	7.493	0.9474	3.05	0.945	0.8903
S2	7.723	0.889	2.787	0.9211	0.8417
S3	7.013	0.9251	2.859	0.9312	0.8639
S4	7.243	0.9473	3.011	0.9445	0.9408
S5	8.051	0.9381	3.092	0.9473	0.9309
S6	8.111	0.9581	3.226	0.9561	0.9411
S7	3.278	0.9773	2.25	0.89	0.8873
S8	6.228	0.9483	2.841	0.9367	0.9443
S9	4.945	0.9377	2.475	0.9058	0.9067
S10	6.392	0.9455	2.832	0.933	0.9211

d=Margalef index, J' = Pielou's evenness, H' = Shannon diversity index, 1-Lambda' = Simpson diversity index, MI = Mortality index

Table 4. Major species which contributed to the resemblance of different sites (Average similarity : 44.81%)

Species	Contribution %
<i>Acropora formosa</i>	19.47
<i>Porites lutea</i>	14.75
<i>Porites lichen</i>	10.73
<i>Platygyra lamellina</i>	9.1
Others (holothurids, anemones, giant clams, other molluscs)	7.13
<i>Acropora palifera</i>	6.2
<i>Pocillopora damicornis</i>	5.97

Table 5. Matrix showing major species discriminating different regions

Groups	North	South	Lagoon	South-east
North	0			
South	<i>Porites cylindrica, Acropora palifera, Porites solida</i>	0		
Lagoon	<i>Acropora palifera, Porites lichen, Porites cylindrica</i>	<i>Porites lichen, Goniastrea retiformis, Porites solida</i>	0	
South-east	<i>Acropora palifera, Platygyra lamellina, Acropora gemmifera</i>	<i>Goniastrea retiformis, Pocillopora eydouxi, Acropora gemmifera</i>	<i>Porites lichen, Porites cylindrica, Acropora tenuis</i>	0

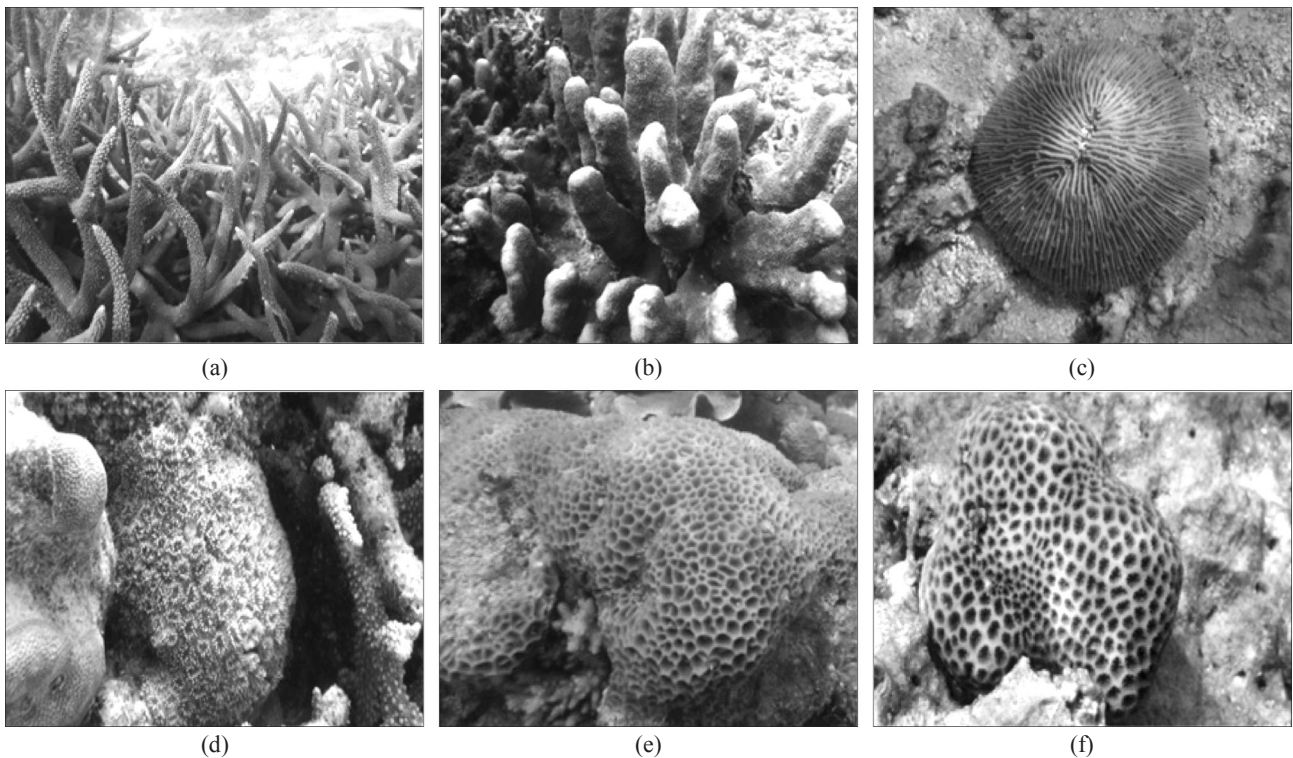


Fig. 3. Selected hard coral species recorded from Agatti Island. (a) *Acropora formosa*, (b) *Acropora palifera*, (c) *Fungia fungites*, (d) *Galaxea fascicularis*, (e) *Gardineroseris planulata*, (f) *Leptastrea purpurea*

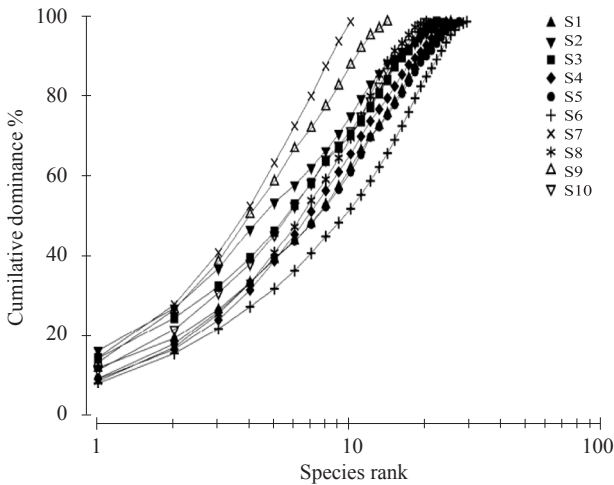
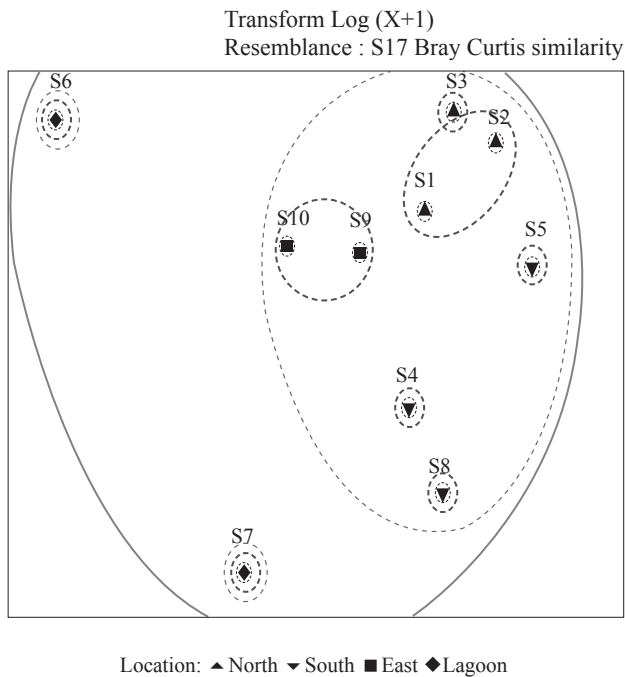


Fig. 4. K-dominance plot for Agatti Island

Table 6. Dissimilarity between western and eastern reefs (Average dissimilarity: 53.56%)

Species	Contribution%
<i>Acropora gemmifera</i>	5.52
<i>Acropora palifera</i>	4.54
<i>Goniastrea retiformis</i>	4.41
<i>Pocillopora eydouxi</i>	4.41
<i>Platygyra lamellina</i>	4.15
<i>Porites solida</i>	4.02
<i>Acropora muricata</i>	3.74
<i>Porites cylindrica</i>	3.7



Location: ▲ North ▼ South ■ East ◆ Lagoon
 Similarity: — 20, - - - 40, . . . 60, - . - . 80

Fig. 5. MDS plot showing similarity between different survey stations

However, these parameters are liable to change due to meteorological or anthropogenic reasons (Sorokin, 1992). Maintaining coral reef populations in the face of large scale degradation and phase-shifts on reefs depend critically on coral recruitment and on sustainable management of coral reefs (Hughes, 1994; Hughes and Tanner, 2000). Diversity can be the indicator of a system’s stability to withstand disturbance (McCann, 2000). Agatti Island reef is one among those invaluable atolls with a highly diverse and structured ecosystem, which needs to be protected from overexploitation and deterioration. Islanders depend on the reefs for 90% of their protein intake (Hoon, 2003). Combined effect of increase in human population density in the island and their increased reliance on the natural resources exert pressure on the ecosystem. Adding to these, natural disturbances and global climate change, calls for considerable management interventions. Actions must be taken to transplant live coral buds (from the same reef) to areas having extensive dead coral cover. Further studies need to be undertaken on the reproduction and natural propagation of hard corals that can act as indicators of reef sustenance in the long run. In addition, genetic studies may be encouraged to find the endemism and overall diversity of hard corals from the island.

Acknowledgements

The authors are grateful to Dr. G. Syda Rao, former Director, ICAR-CMFRI, Kochi and Dr. A. Gopalakrishnan, Director, ICAR-CMFRI, Kochi for the encouragement and support. Acknowledgements are also due to the Director, Department of Science and Technology (DST), Govt. of India for providing permission and facilities to conduct survey in the Island.

References

Arthur, R. 2000. Coral bleaching and mortality in three Indian reef regions during an El Niño southern oscillation event. *Curr. Sci.*, 79 (12): 1723-1729.

Arthur, R., Done, T. J., Marsh, H. and Harriott, V. 2006. Local processes strongly influence post-bleaching benthic recovery in the Lakshadweep Islands. *Coral Reefs*, 25: 427-440.

Arthur, R., Done, T. J. and Marsh, H. 2005. Benthic recovery four years after an El Niño induced coral mass mortality in the Lakshadweep atolls, *Curr. Sci.*, 89(4): 694-699.

Bahuguna, A., Ray Chaudhury, N., Bhattji, N. Ajai and Navalgund, R. R. 2013. Spatula inventory and ecological status of coral reefs of the Central Indian Ocean using Resourcesat-1. *Indian J. Geo-Mar. Sci.*, 42(6): 684-696.

Bahuguna, A. and Nayak, S. 1994. Coral reef mapping of the Lakshadweep Islands. Space Application Centre, Ahmedabad, India. *Scientific note SAO/RSA/R DAG-DOD-COS/SN/09* 20 pp.

- Bray, J. R. and Curtis, J. T. 1957. An ordination of the upland forest communities of Southern Wisconsin. *Ecol. Monogr.*, 27: 325-349.
- Buddemeier, R. W., Kleupas, J. A. and Aronson, R. B. 2004. Coral reefs and global climate change: Potential contributions of climate change to stresses on coral reef ecosystems *Report prepared for the Pew Centre on Global Climate Change*, Arlington, Virginia, USA, 56 pp.
- Carr, M. R. 1996. *Plymouth routines in Multivariate Analysis. Primer user manual*. Natural Environment Research Council, Swindon, UK, 91 pp.
- Clarke, K. R. 1993. Non-parametric multivariate analyses of changes in community structure. *Aust. J. Ecol.*, 18: 117-143.
- COREMAP-AMSAT 2001. Optimisation of survey design for reef health monitoring. *COREMAP BME Report 2*. COREMAP Secretariat, Jakarta, Indonesia, 33 pp.
- Costanza, R., d'Arge, R., deGroot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., Oneill, R. V., Paruelo, J., Raskin, R. G., Sutton, P. and van den Belt, M. 1997. The value of the world's ecosystem services and natural capital. *Nature*, 387: 253-260.
- Crabbe, M. J. C., Martinez, E., Garcia, C., Chub, J., Castro, L. and Guy, J. 2008. Growth modeling indicates hurricanes and severe storms are linked to low coral recruitment in the Caribbean. *Mar. Environ. Res.*, 65: 364-368.
- Crabbe, M. J. C., Martinez, E., Garcia, C., Chub, J., Castro, L. and Guy, J. 2009. Identifying management needs for coral reef ecosystems. *Sustainability: science, practice policy*, 5(1).
- Darwin, C. 1842. *The structure and distribution of coral reefs*. Smith, Elder and Co, London, 214 pp.
- Department of Planning and statistics 2002. *Basic statistics 2001-2002*, Secretariat, UT Lakshadweep, Kavaratti.
- Done, T. J. 1992. Phase shifts in coral reef communities and their ecological significance. *Hydrobiologia*, 247: 121-132.
- English, S., Wilkinson, C. and Baker, V. 1997. *Survey manual for tropical marine resources*, 2nd edn. Australian Institute of Marine Science, Townsville, Australia, 390 pp.
- Gardiner, J. S. 1904. Madreporaria Pt. 2. Astreidae. *Fauna and geography of the Maldive and Laccadive Archipelagos*, vol. 2 (758-790): 59-64.
- Gardiner, J. S. 1905. Madreporaria Pt. 3. Fungidae. *Fauna and geography of the Maldive and Laccadive Archipelagos*, vol. 2 (933-957): 89-93.
- George, A. M. 2008. Abundance and community structure of reef building corals in Lakshadweep Islands, India. *Atoll Res. Bull.*, 563: 1-14.
- Gini, C. 1912. Variabilità e mutabilità. In: Pizetti, E. and Salvemini, T. (Eds.), Reprinted in *Memorie di metodologica statistica, Libreria Eredi Virgilio Veschi*, Rome.
- Gomez, E. D. and Alcalá, A. C. 1979. Status of Philippine coral reefs. In: *Proceedings of the International Symposium on Marine Biogeography and Evolution in the Southern Hemisphere*, 17-20 July 1978, Auckland, New Zealand. DSIR Inf. Ser. v.137, p. 645-661.
- Gomez, E. D., Alino, P. M., Yap, H. T. and Lieuanan, W. Y. 1994. A review of the status of Philippine reefs. *Mar. Pollut. Bull.*, 29: 62-678.
- Hoon, V., Abdul Shukoor, B., Moosa, O. G., Ayoob, A. E., Cheriakoya, M. I., Mohammad Ali, M. C., Hajara, A., Moosakoya, B., Tajunnissa, N. M. and Aboobacker, P. P. 2002. Socio-economic assessment and monitoring of coral reefs of Agatti Island, UT of Lakshadweep. *Project Completion Report, CARESS*, Chennai, India, p. 1-83.
- Hoon, V. 2003. A case study on Lakshadweep Islands. In: Wittingham E., Campbell J. and Townsley. P. (Eds.), *Poverty and coral reefs: vol. 2, Case studies*, DFID, IMM-IOC/UNESCO, 260 pp.
- Hoon, V. and Tamelander, J. 2005. Community based monitoring of coral reef resource use. *CORDIO status report*, 2005.
- Hughes, T. P. 1994. Catastrophes, phase shifts and large scale degradation of a Caribbean coral reef. *Science*, 265: 1547-1551.
- Hughes, T. P. and Tanner, J. E. 2000. Recruitment failure, life histories and long-term decline of Caribbean corals. *Ecology*, 81(8): 2250-2263.
- James, P. S. B. R. 1989. History of marine research in Lakshadweep. *CMFRI Bull.*, 43: 9-25.
- James, P. S. B. R. 2011. The Lakshadweep: Islands of ecological fragility, environmental sensitivity and anthropogenic vulnerability. *J. Coast. Env.*, 2(1): 9-25.
- Jones, S. 1986. Lakshadweep – general features and some considerations. *Mar. Fis. Inf. Serv. T&E Ser.*, 68: 3-6.
- Kumar, T. T. A. and Balasubramanian, T. 2012. Bleaching of corals in Agatti-Lakshadweep, India: a window view. In: *Proceedings of the 12th International Coral Reef Symposium*, 9A Coral Bleaching and Climate Change, Cairns, 9-13 July 2012, Australia.
- Lambshhead, P. J. D., Platt, H. M. and Shaw, K. M. 1983. The detection of differences among assemblages of marine benthic species based on an assessment of dominance and diversity. *J. Nat. Hist.*, 17: 859-874.
- Margalef, D. R. 1958. Information theory in ecology, *Gen. Syst.*, 3: 36-71.
- McCann, K. S. 2000. The diversity-stability debate. *Nature*, 405: 228-233.
- McCook, L. J. 1999. Macroalgae, nutrients and phase shifts on coral reefs: Scientific issues and management consequences for the Great Barrier Reef. *Coral Reefs*, 18: 357-367.
- Nagabhushanam, A. K. and Rao, G. C. 1972. An ecological survey of the marine fauna of Minicoy Atoll (Laccadive Archipelago, Arabian Sea). *Mitt. Zool. Mus. Berlin*, 48(2): 265-324.
- Pielou, E. C. 1977. *Mathematical ecology*, John Wiley and Sons, New York, 385 pp.

- Pillai, C. S. G. 1967a. Studies on Indian corals I. Report on a new species of *Montipora* (Scleractinia, Acroporidae). *J. Mar. Biol. Assoc. of India*, 9 (2): 399-401.
- Pillai, C. S. G. 1967b. Studies on Indian corals 2. Report on a new species of *Goniopora* and three new species of *Porites* (Scleractinia, Poritidae). *J. Mar. Biol. Assoc. India*, 9(2): 402-406.
- Pillai, C. S. G. 1967c. Studies on Indian corals 5. Preliminary reports on new records of hermatypic corals of the suborder Astrocoeniina. *J. Mar. Biol. Assoc. India*, 9(2): 412-422.
- Pillai, C. S. G. 1973. A review of the genus *Acropora* (Scleractinia, Acroporidae) with the description of a new species. *J. Mar. Biol. Assoc. India*, 15: 296 - 301.
- Pillai, C. S. G. 1983a. Structure and generic diversity of recent scleractinia of India. *J. Mar. Biol. Assoc. India*, 25 (1& 2): 78-90.
- Pillai, C. S. G. 1983b. The endangered marine and terrestrial habitats of Minicoy Island in Lakshadweep – A matter of concern for naturalists. *Proceedings of the Seminar on World Conservation*, Bombay Natural History Society, December 1983, p. 24-28..
- Pillai, C. S. G. 1986. Status of coral reefs in Lakshadweep. *Mar. Fish. Inf. Serv. T&E Ser.*, 68: 38-41.
- Pillai, C. S. G. 1996. Coral reefs of India, their conservation and management. In: Menon, N. G. and Pillai, C. S. G. (Eds.). *Marine biodiversity: conservation and management*, CMFRI, Kochi, p. 16-31.
- Pillai, C. S. G., and Jasmine, S. 1989. The coral fauna. In: *Marine living resources of the Union Territory of Lakshadweep: An indicative survey with suggestions for development*. CMFRI Bull., 43: 179-194.
- Pillai, C. S. G and Scheer, G. 1976. Report on the stony corals from the Maldive Archipelago. *Zoologica*, 126:1-83.
- Raghuraman, R., Sreeraj, C. R., Raghunathan, C. and Venkataraman, K. 2012. Scleractinian coral diversity in Andaman and Nicobar Islands in comparison with other Indian Reefs In: *Proceedings of International day for Biological Diversity: Marine Biodiversity*, Uttar Pradesh State Biodiversity Board, p. 75-92.
- Raheem, C. N. A. 2012. Status of coral reefs of Lakshadweep In: Bhatt, J. R., Patterson Edward, J. K., Macintosh D. J. and Nilaratna, B. P. (Eds.), *Coral reefs in India - status, threats and conservation measures*, IUCN, India, p. 37-44.
- Reaka-Kudla, M. L. 1997. Global biodiversity of coral reefs: a comparison with rainforests. In: Reaka-Kudla, M. L. and Wilson, D. E. (Eds.), *Biodiversity II: Understanding and protecting our biological resources*. Joseph Henry Press, p. 83-108.
- Reaka-Kudla, M. L. 2001. Known and unknown biodiversity, risk of extinction and conservation strategy in the sea. In: Bendell-Young, L. and Gallagher, P. (Eds.), *Global waters in peril*, Kluwer Academic Publishers, New York, p.19-33.
- Rilov, G. and Benayahu, Y. 1998. Vertical artificial structures as an alternative habitat for coral reef fishes in disturbed environments. *Mar. Environ. Res.*, 45: 431-451.
- Shannon, C. E. and Weaver, W. 1949. *The mathematical theory of communication*, University of Illinois Press, Urbana, Illinois, 125 pp.
- Simpson, E. H. 1949. Measurement of diversity. *Nature*, 163: 688.
- Sorokin, Y. I. 1992. *Coral reef ecology: Ecological studies*, Springer Verlag, Berlin, Heidelberg, 465 pp.
- Suresh, V. R. 1991. *Studies on coral reefs of Lakshadweep*, Ph. D. Thesis, Cochin University of Science and Technology, Kochi, India, 123 pp.
- Suresh, V. R. and Mathew, K. J. 1993. Skeletal extension of staghorn coral *Acropora formosa* in relation to environment at Kavaratti Atoll (Lakshadweep). *Indian J. Mar. Sci.*, 22: 176-179.
- Tamelandar, J. and Rajasuriya, A. 2008. Status of coral reefs in South Asia: Bangladesh, Chagos, India, Maldives and rilanka, In: Wilkinson, C. (Ed.), *Status of coral reefs of the world*, Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, p.119-130.
- Venkataraman, K., Satyanarayana, Ch., Alfred, J. R. B. and Wolstenholme, J. 2003. *Handbook on hard corals of India*. Zoological Survey of India, Kolkata, 266 pp.
- Veron J. E. N. 2000. *Corals of the world, vol.1-3*. Australian Institute of Marine Science. Townsville, Australia, p.1382.
- Veron, J. E. N. 1986. *Corals of Australia and Indo-Pacific*. Australian Institute of Marine Science, Townsville, Australia, 644 pp.
- Veron, J. E. N. 2000. *Corals of the world, vol. 1, 2 and 3*. Australian Institute of Marine Science, Townsville, Australia, p. 429-490.
- Vivekanandan, E., Ali, M. H., Jasper, B. and Rajagopalan, M. 2008. Thermal thresholds for coral bleaching in the Indian seas. *J. Mar. Biol. Assoc. India*, 50(2): 209-214.
- Wafar, M. V. M. 1999. Status report India. In: Linden, O. and Sporrang, N. (Eds.), *CORDIO Status Report.*, p. 25-26.
- Wallace, C. C. 1999. *Staghorn corals of the world - A revision of the coral genus Acropora (Scleractinia; Astrocoeniina; Acroporidae) worldwide, with emphasis on morphology, phylogeny and biogeography*. CSIRO Publishing, Collingwood, Australia, 438 pp.
- Wells, S. M. 1988. *Coral reefs of the world, vol. 2: Indian Ocean, Red Sea and the Gulf*. UNEP Nairobi; International Union for Conservation of Nature and Natural Resources, Switzerland.

Date of Receipt : 03.07.2014

Date of Acceptance : 04.03.2015