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Assessment of the spatial variation in the macro-algal resources of Lakshadweep, India

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Original Article

Abstract

Marine macroalgae play a vital functional role as primary producers in the marine environment. The present article reports a significant spatial variation in the macroalgal resources of different zones of the atoll, like the intertidal zone, lagoon, inner reef slope, reef crest, outer reef slope, and reef flat. The study was carried out from October 2015 to October 2019 to record the occurrence and abundance of macroalgae from intertidal zones to 25 m depth, covering ten inhabited and two uninhabited islands of Lakshadweep Archipelago. In the present study, 65 species of marine macroalgae belonging to 22 families under three phyla, Rhodophyta, Chlorophyta and Phaeophyta, were recorded from Lakshadweep. The four species, *Botryocladia pseudodichotoma, Gracilaria parvispora, Sargassum polycystum* and *Valonia ventricosa,* are new records to Lakshadweep.

Keywords*: Seaweed, seagrass, Lakshadweep, biogeographic zone, algae, new records*

Introduction

Marine algae are ecologically and biologically essential components in marine ecosystems. Algae contribute significantly to marine primary production and provide habitat for nearshore benthic communities (Mann, 1973; Williams and Smith, 2007). Macroalgae are seen in the intertidal and subtidal region up to a depth, where 0.01 % photosynthetic light is available (Domettila *et al*., 2013). Marine algae are valuable renewable living resources for humans and are a highly diversified tropical species. Algae are commonly found on hard substrata like rocks, pebbles, dead corals, and shells up to a maximum depth of 180m with abundance in the shallow coastal bottom. Chlorophyta (Green algae), Phaeophyta (Brown algae) and Rhodophyta (Red algae) are three phyla of macroalgae. These three groups of macroalgae are significant as many industrial products such as agar, alginate, and carrageenan can also extract from them. Seaweeds are used as animal feed, manure and as sources of enzymes, dyes, drugs, minerals, and vitamins (Chapman, 1970; Deve *et al*., 1977; Joseph and Lipton, 2004). Recent comprehensive estimates of global diversity reported 72,500 taxa; 44,000 have already been described (Guiry, 2012). The most comprehensive account for Indian waters reported that 841 species belong to 216 genera of 68 families present in Indian waters (Oza and Zaidi, 2001). However, a recent study estimated 871 species of macroalgae from Indian waters (Kaliaperumal, 2017). Devaraj *et al.* (1999) reported the total standing crop of seaweeds in the Indian waters as more than one hundred thousand tons in wet weight. Various institutions did earlier work on resources assessment of seaweeds in Lakshadweep reef (Anon, 1978; Untawale *et al.,* 1983 and Kaliaperumal *et al.,* 1989 a,b), which was reviewed by Kaladharan (2001) and reported nearly 10,000-19,000 tonnes wet weight, which comprises 114 species belonging to 62 genera in these atolls. Anuradha *et al.* (2015) evaluated the biochemical and nutritional potential of seaweeds from the Lakshadweep Archipelago to document the variation of the proximate composition and mineral content of nine macroalgae in these groups of islands to assess their nutritional quality. However, the studies on distribution patterns and spatial variations in the macroalgal resources in Lakshadweep are limited. The present study has attempted to assess the distribution of macroalgae in various islands and different geomorphologic zones of these atolls. The present study can help to formulate site-specific resource characteristics and distribution patterns of macroalgae in and around the reefs of this Archipelago.

Material and methods

We conducted exploratory surveys in ten inhabited islands and two uninhabited islands in Lakshadweep from October 2015 to October 2019 (Table 1 and Fig. 1). Surveys were conducted to assess the diversity of macroalgae in different atolls like intertidal zone, lagoon, inner reef slope, reef crest, outer reef slope, and reef flat, using snorkelling and SCUBA. The specimens were photographed to document the habitat to show the environmental conditions and the general view of the algal association. Collected specimens are preserved by fixing in a 3-5 % formalin-seawater mix and kept as herbarium vouchers. The seaweeds were identified using the taxonomic keys based on the Algaebase (www.algaebase.org) and the identification key provided by Rao (1987). The following references were used to confirm the identity of the new records (Agardh, 1823; Olsen and West, 1998; Abbott, 1985; Phang *et al*., 2008). Specimens are labelled adequately with the collection date, locality, and time for further reference and deposited in the Marine Taxonomy Reference Laboratory (MTRL), Department of Science and Technology Union Territory of Lakshadweep.

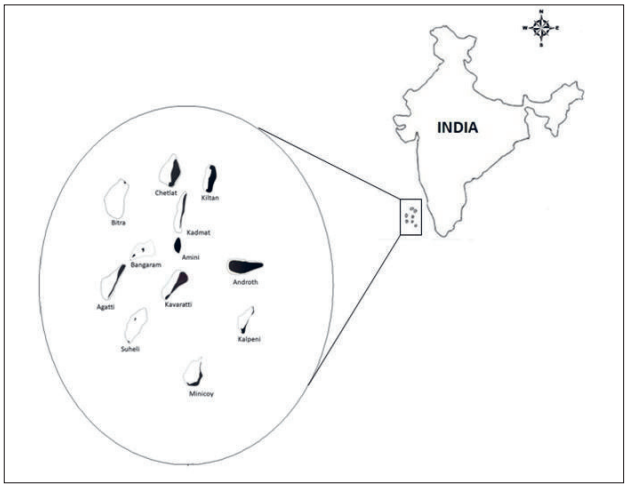

Fig. 1. Map of Lakshadweep Archipelago.

Results

During the present study, 65 species of marine macroalgae belonging to 22 families under three phyla, Rhodophyta, Chlorophyta and Phaeophyta, were recorded from Lakshadweep. The four species, *Botryocladia pseudodichotoma, Gracilaria parvispora, Sargassum polycystum* and *Valonia ventricosa,* are new records to Lakshadweep (Table 2). Marine macroalgae were distributed mainly on rubbles and rocky substrata, which comprise sand, mud, rocks, pebbles, and sand-mud mixtures in this reef region. Higher macroalgae species diversity was observed in the Kavaratti reef (44 species), followed by the Androth reef, contributing 37 species. The maximum species contribution is exhibited by Chlorophyta (31 species), followed by Rhodophyta (21 species) and Phaeophyta (13 species) in this reef. The occurrence of macroalgae was higher in the lagoon and intertidal regions, with sandy, coral and rocky habitats contributing 80% of species to the reef.

The sighting frequency of macroalgae showed a marked variation between different atoll reefs of Lakshadweep. The distribution pattern, community structure, and spatial variation of macroalgae also exhibited the same trend between the intertidal zone, lagoon, inner reef slope, reef crest, outer reef slope, and reef flat. The present study also recorded that the species like *Asparagopsis taxiformis* and *Boergesenia forbesii* were found distributed in all the atolls. Similarly, the species *Padina pavonica* showed dominance in many atolls studied. In contrast, some species like *Galaxaura rugosa, Gracilaria parvispora, Botryocladia pseudodichotoma, Cladophoropsis javanica, Valonia ventricosa*

Table 1. Locations, lagoon area and number of transects surveyed in various islands

No.	Island	Latitude	Longitude	Lagoon Area	No. of transects observed
1	Kavaratti	10.567617°	72.639217°	4.9 km^2	44
2	Agatti	10.863916°	72.196539°	17.5 km^2	26
3	Bangaram group of islands	10.939555°	72.287188°	46.2 km^2	23
4	Bitra	11.583333°	72.167183°	45.6 km^2	27
5	Chetlat	11.694183°	72.706683°	1.6 km^2	23
6	Kiltan	11.483533°	73.000650°	1.7 km^2	23
7	Kalpeni	10.091883°	73.630817°	25.6 km^2	30
8	Minicoy	8.273841°	73.050707°	30.6 km^2	30
9	Kadmat	11.222645°	72.777167°	37.5 km^2	28
10	Androth	10.815883°	73.671750°	0	27
11	Amini	11.122650°	72.719183°	1.5 km^2	22
12	Suheli	10.066600°	72.292100°	87.8 km^2	27

Table 2. Occurrence of marine macroalgae in various islands of Lakshadweep Archipelago

	Division	Family	Species Name	Kvt	Agt	Bng	Btr	Cht	Klt	Klp	Mcy	Kdt	And	Amn	Suh
1	Rhodophyta	Bonnemaisoniaceae	*Asparagopsis taxiformis*	*	*	*	*	*	*	*	*	*	*	*	*
2		Ceramiaceae	*Centroceras clavulatum*	*	*	*	-	-	-	–	-	*	*	-	*
3			*Ceramium* sp.	-	-	-	-	-		-	-	*	-	-	-
4		Lithophyllaceae	*Amphiroa anastomosans*	*	*	-	*	*	-	*	–	-	*	–	-
5			*Amphiroa* sp.	-	-	-	-	*	-	-	-	-	-	-	-
6		Corallinaceae	*Jania adhaerens*	*	*	*	-	-	-	*	*	-	*	-	-
7			*Jania capillacea*	*	*	-	-	-	-	-	-	-	*	-	-
8		Cystocloniaceae	*Hypnea musciformis*	*	*	-	-	-	*	*	*	*	*	-	*
9			*Hypnea pannosa*	*	*	*	-	*	*	*	*	-	*	-	*
10			*Hypnea valentiae*	*	*	*	-	-	-	-	*	-	*	-	-
11		Derbesiaceae	*Derbesia turbinata*	-	-	-	-	-	-	*	-	-	-	-	-
12		Gracilariaceae	*Hydropuntia edulis*	*	*	-	-	*	*	*	*	-	*	*	-
13			*Gracilaria parvispora***	*	-	-	-	-	-	-	-	-	-	-	-
14			*Gracilaria* sp.		-	-	-	-	-	*	-	-	-	-	-
15		Galaxauraceae	*Galaxaura rugosa*	*	-	-	-	-	-	-	-	-	-	-	-
16		Gelidiellaceae	*Gelidium pusillum*	*	*	*	-	*	*	*	-	-	*	-	*
17			*Gelidiella acerosa*	*	*	-	*	*	*	*	-	-	*	*	*
18		Lomentariaceae	*Ceratodictyon repens*	*	-	-	-	*	-	*	*	*	*	*	-
19		Rhodomelaceae	*Acanthophora spicifera*	*	*	*	-	-	*	*	*	*	*	-	*
20			*Laurencia papillosa*	*	*	-	-	*	*	*	-	*	*	-	-
21			*Botryocladia pseudodichotoma***	*	-	-	-	-	-	-	-	-	-	-	-
22	Chlorophyta	Bryopsidaceae	*Bryopsis pennata*	*	*	*	-	*	*	*	*	-	*	-	*
23			*Bryopsis plumosa*	*	*	-	-	*	*	*	*	*	-	-	-
24		Caulerpaceae	*Caulerpa racemosa*	*	*	*	*	*	*	*	*	*	*	*	-
25			*Caulerpa scapelliformis*	*	*	-	-	-	*	*	-	-	*	*	-
26			*Caulerpa chemnitzia*	*	*	-	-	-	-	-	-	-	*	-	-
27			*Caulerpa serrulata*	*	*	-	-	-	*	*	*	-	*	*	-
28			*Caulerpa macra*	-	-	-	-	*	-	-	-	-		-	-
29			*Caulerpa macrophysa*	-	-	-	-	-	-	*	-	-	-	-	-
30		Cladophoraceae	*Chaetomorpha linum*	*	*	*	-	*	*	*	-	*	*	-	-
31			*Chaetomorpha spiralis*	-	-	-	-	-	*	-	-	-	-	-	-
32			*Chaetomorpha ligustica*	-	-	-	-	-	-	-	*	-	-	-	-
33			*Chaetomorpha crassa*	-	-	-	-	-	*	-	-	-	-	-	-
34			*Cladophoropsis javanica*	*	-	-	-	-	-	-	-	-	-	-	-
35			*Cladophora vagabunda*	-	-	-	*	-	-	-		-	-	-	-
36			*Cladophora* sp.	-	-	-	-	-	-	-	*	-	-	*	-
37		Codiaceae	*Codium fragile*	*	*	-	*		*	-	-	-	*	–	-
38		Halimedaceae	*Halimeda incrassata*	*	-	-	-	-	-	-	*	*	*	-	-
39			*Halimeda tuna*	*	-	*	-	-	-	*	-	*	*	-	-
40			*Halimeda minima*	*	*	-	*	-	*	-	-	*	*	-	*
41			*Halimeda macroloba*	*	-	-	-	*	*	-	-	*	-	-	-
42			*Halimeda gracilis*	-	-	-	-	-	-	-	*	-	-	-	-
43		Oscillatoriaceae	*Lyngbya majuscula*	-	-	-	-	-	-	-	*	-	-	-	*

	Division	Family	Species Name	Kvt	Agt	Bng	Btr	Cht	Klt	Klp	Mcy	Kdt	And	Amn	Suh
44		Siphonocladaceae	*Boergesenia forbesii*	*	*	*	*	*	*	*	*	*	*	*	*
45		Ulvaceae	*Ulva lactuca*	*	*	*		*	*	*	*	*	*	*	-
46			*Ulva intestinalis*	*	*	*	-	*	*	*	-	*	*	*	-
47			*Ulva compressa*	*	*	-	-	-	*	-	-	*	*	*	-
48		Valoniaceae	*Valonia aegagropila*	*	*	-	-	-	-	-	-	-	*	-	-
49			*Valonia fastigiata*	*	-	-	-	-	-	-	-	-	*	-	-
50			*Valonia ventricosa***	*	-	-	-	-	-	-	-	-	-	-	-
51			*Valoniopsis pachynema*	-	-	-	-	-	-	*	-	-	-	-	-
52			*Valonia* sp.	-	-	-	-	-	-	-	*	-	-	-	-
53	Ochrophyta	Dictyotaceae	*Padina pavonica*	*	*	*	*	*	*	*	*	-	*	*	*
54			*Padina tetrastromatica*	*	*	*	*	*	*	*	*	-	*	*	*
55			*Canistrocarpus cervicornis*	-	-	-	-	-	-	-	*	-	-	-	-
56			*Dictyota dichotoma*	-	-	-	-	-	*	-	-	-	-	-	-
57			*Dictyota divaricata*	*	-	-	-	-	-	-	-	*	-	-	-
58			*Dictyopteris delicatula*	-	-	-	-	-	-	-	*	-	-	-	-
59		Sargassaceae	*Turbinaria ornata*	*	*	*	*		*	*	*	*	*	*	*
60			*Turbinaria turbinata*	*	*	-	-		*	-	-	*	*	*	*
61			*Turbinaria conoides*	*	*	*	*		-	*	-	-	*	*	-
62			*Turbinaria decucrrence*	*	*	*	-		*	*	-	-	*	*	-
63			*Sargassum ilicifolium*	-	-	-	-	-	-	*	-	*	-	-	-
64			*Sargassum polycystum***	-	-	-	-	-	-	-	-	-	*	-	-
65			*Sargassum* sp.	-	-	-	-	*	-	-	-	-	-	-	-

*Collected and identified during the present study,** New records of Species, Kvt. Kavaratti, Agt. Agatti, Beg. Bengaram, Btr. Bitra, Cht. Chetlat, Klp. Kalpeni, Mcy. Minicoy, Kdt. Kadmat, And. Androth, Amn. Amini, and Suh. Suheli. Klt. Kiltan.

and *Dictyota divaricata* exhibited restricted distribution in Kavaratti Island. The species like *Derbesia turbinata, Gracilaria* sp. and *Valoniopsis pachynema* were observed in Kalpeni Island only, and species like *Chaetomorpha ligustica, Dictyopteris delicatula, Halimeda gracilis, Lyngbya majuscula* and *Valonia* sp. were distributed in Minicoy Island only (Table 2).

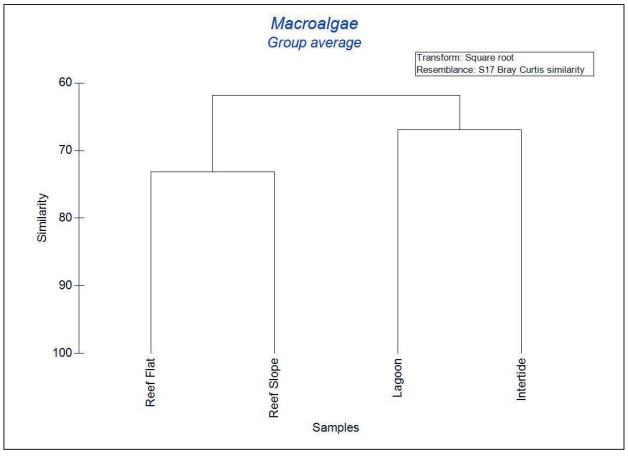

Fig. 2. Dendrogram showing the similarities in the occurence of marine macroalgae in various biogeographic zones of the Lakshadweep Archipelago.

Cluster analysis showed a spatial variation in the distribution and abundance of macroalgae in different biogeographic regions of the atolls. The similarity in the macroalgal assemblage in different biogeographic regions of selected atolls of Lakshadweep Archipelago is shown in Fig. 2. Seventy-four percentage similarity was observed in the occurrence and distribution of macroalgae in reef slope and reef flat. Spatial variation patterns of macroalgae in the lagoon area showed a 70 % similarity with reef slope and reef flat. In comparison, the intertidal zone exhibited only 57.1% similarities between the other three zones of the atoll. The distribution pattern of macroalgae from the Kadmat reef slope is distinctly different from other island areas; the Amini reef slope is dissimilar to other biogeographic regions.

Discussion

In Lakshadweep reefs, macroalgae are found attached to the solid bottom substrate like rocks, dead corals, pebbles, shells, and other plant materials, which showed a marked difference in the atoll reefs of Lakshadweep. It may be due to the preference of macroalgae to get attached to the available solid bottom substratum. At the same time, macroalgae grow

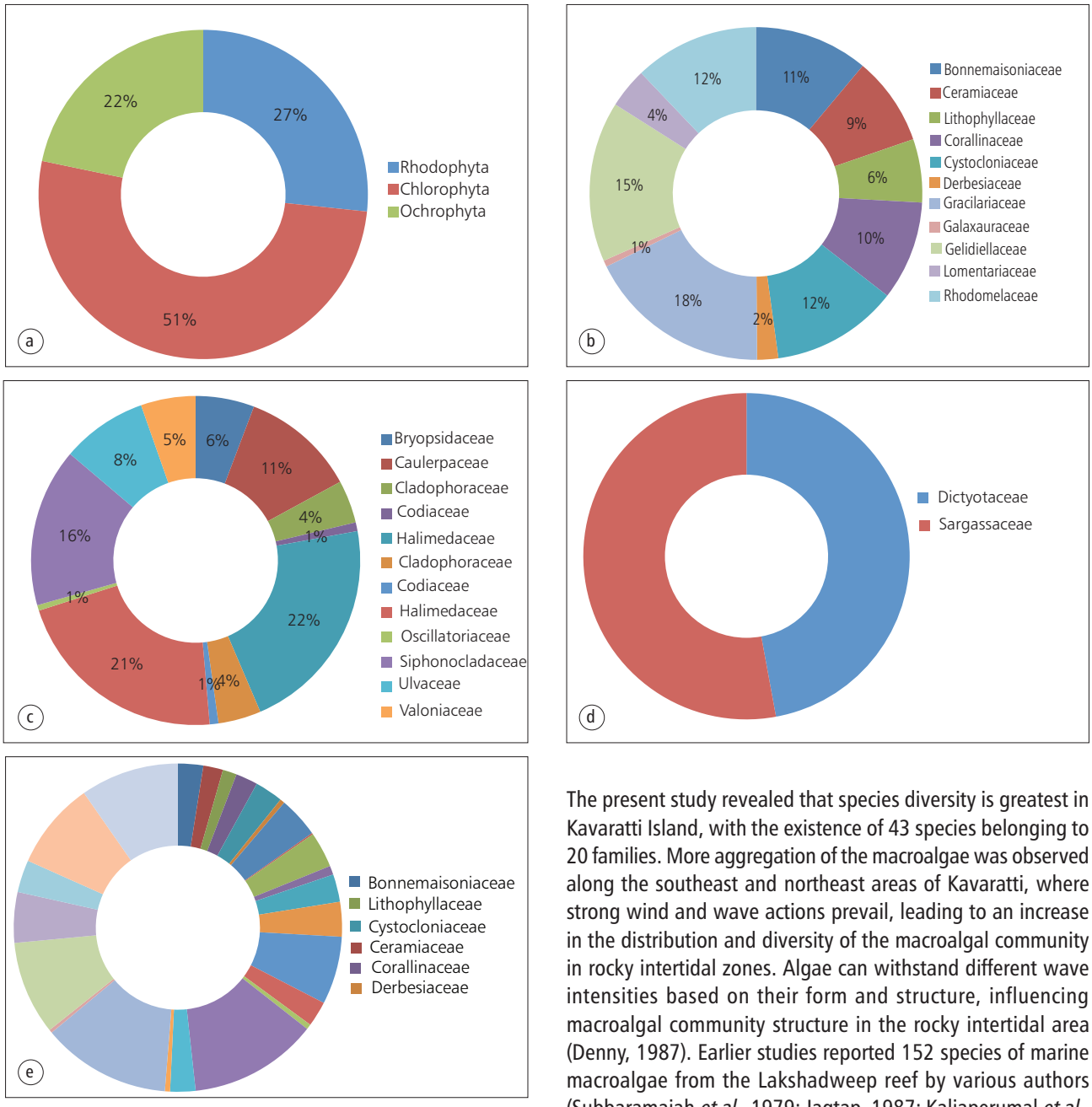

Fig. 3. Contribution of different taxa to the total assemblage of macroalgae in Lakshadweep Archipelago. a. Order wise percentage occurrence, b. Order Rhodophyta, family-wise percentage contribution c. Order Chlorophyta, family-wise percentage contribution, d. Order Ochrophyta, family-wise percentage contribution and e. overall family-wise percentage occurrence

on hard substrates (*e.g.*, dead coral, rock) or epiphytically or on other animals using holdfasts to anchor themselves (Macreadie *et al.*, 2017). Marine macroalgae live either in marine or brackish water environments. They perform vital ecological functions like reef structure stabilisation, production of tropical sands, nutrient maintenance and recycling, and primary productivity (Fong and Paul, 2011).

The present study revealed that species diversity is greatest in Kavaratti Island, with the existence of 43 species belonging to 20 families. More aggregation of the macroalgae was observed along the southeast and northeast areas of Kavaratti, where strong wind and wave actions prevail, leading to an increase in the distribution and diversity of the macroalgal community in rocky intertidal zones. Algae can withstand different wave intensities based on their form and structure, influencing macroalgal community structure in the rocky intertidal area (Denny, 1987). Earlier studies reported 152 species of marine macroalgae from the Lakshadweep reef by various authors (Subbaramaiah *et al.*, 1979; Jagtap, 1987; Kaliaperumal *et al.*, 1989 a,b); however, the present study could record only 65 species from this reef. The decline of the macroalgal distribution in this region is by the degradation of the macroalgal community due to natural and anthropogenic issues. Moreover, the drastic decline of seagrass and seagrass meadows, coupled with global warming and climate change, may accelerate the quick loss of the macroalgal community in this reef (Norkko and Bonsdorff, 1996).

Rhodophyta is the abundant macroalgal taxa in the intertidal region of Lakshadweep reefs, followed by Chlorophyta and Phaeophyta (Fig. 3). Rhodophyta can colonise in an

area with a wide range of light, temperature, and energy conditions and remain the chief components of benthic marine communities in the intertidal zone (McCoy and Nicholas, 2015). Rhodophyta integrates ecological, physiological, and geochemical responses to global change in terms of a wide range of light, temperature, and energy conditions and remaining chief components of benthic marine communities through considerable fluctuations in temperature and light over geologic time (Aguirre *et al*., 2000). The higher diversity of Rhodophyta in various Lakshadweep islands can be attributed to their higher adaptability and higher capacity of integration to climatic changes. Kamboj *et al.* (2019) reported a showed marked variation in the distribution of macroalgae in a different region of the Indian coast; the Gulf of Katchch showed a total of 151 species of macroalgae comprised of Chlorophyta (44 species), Phaeophyta (31) and Rhodophyta (76). In the Gulf of Mannar, a total of 22 species of macroalgae comprising of four species of Chlorophyta, nine species of Phaeophyta and nine species of Rhodophyta are recorded (Malathi *et al*., 2018). At the same time, Andaman Nicobar showed 16 species of macroalgae from six Chlorophyta species, six Phaeophyta species, and four Rhodophyta species (Prasanta, 2019), respectively.

The present article documents the preliminary data on the general profile of occurrence, distribution and diversity of macroalgae in different reef zones. Spatial variations are also brought out for this atoll reef covering all the zones, including marginal stretches along the reef flat, seagrass beds and coral sandstones at the lower intertidal region along the shore. The previous studies are restricted to the quantitative description of the macroalgal resource in terms of the economic point of view (Rao, 1969; Rao and Kalimuthu, 1972; Kalimuthu, 1980; Chennubhotla *et al*., 1982; Kaladharan, 2001). The Cluster analysis showed the similarity and dissimilarity in the community structure of macroalgae in various biogeographic regions of the atolls (Fig. 4). The macroalgae of this atoll are highly productive and may play a significant role in reef-building to support the formation of a healthy coral reef. The benthic morphology of coral reefs influences the distribution pattern of marine macroalgae and their community structure (Dawson, 1966).

The distribution pattern of macroalgae at the Amini reef slope and Kadmat reef slope is distinctly different. Generally, the variations within and between the biogeographic regions of the atolls showed 75.4 % and 70.12% dissimilarity, respectively. This dissimilarity may be due to the restricted distributions or absence of macroalgae at the reef slope of Amini and Kadmat atolls compared to other atolls. The occurrence of fishes like Surgeonfishes and Parrotfishes is more in the reef slope of Amini and Kadmat atolls; these herbivorous fish may be responsible for preventing algal accumulation on these reefs. Herbivores strongly influence the biomass, productivity and community composition of seagrass meadows through both direct and indirect mechanisms (Duffy *et al*., 2003; Heck and Valentine, 2006; Lewis and Anderson, 2012; Atwood *et al*., 2015; Cernohorsky *et al*., 2015)

Previous studies revealed that the Lakshadweep Archipelagos is a very productive ecosystem with diverse and abundant macroalgal assemblage with large patches of seaweeds and extensive dense seagrass beds (Jagtap *et al*., 1999). However, earlier studies have not worked out a zone-wise variation in the macroalgal assemblage for these islands. The wide range of seagrass beds and coral sandstones forms a suitable substratum for the attachment of marine macroalgae. The zone-wise similarity in patterns of community structure may be due to the presence of a suitable substratum and solar illumination, which determine the occurrence of different macroalgae. The important parameters regulating algal growth are nutrient quantity and quality, light intensity, pH, wave action, substrate types, temperature and herbivory (Daud *et al*., 2015)

The baseline information on the distribution of macroalgae in different geomorphologic zones of the atolls of Lakshadweep can help to develop an appropriate conservation strategy for this essential natural resource. High diversity was observed in the intertidal area of the southeastern side of Kavaratti Island; the area with a high diversity of macroalgae should be restricted and protected as a community bio-reserve so that the entire associated and immigrant community can be conserved. These softbottom systems, including seagrasses and low-density algal mats, are essential for the habitats, a nursery for fish and substrate to attach sessile organisms, shelter from predation, food supply, and amelioration of adverse stresses such as desiccation (Norkko, 1998; Norkko *et al.,* 2000). Most areas with an abundance of macroalgae have minimal anthropogenic activity, however, macroalgae showed minimal abundance in regions with most disturbances like sand mining and tourism These activities can be made sustainable by creating awareness among the stakeholders on these unique habitats, and with their involvement, the area can be protected and co-managed. With the involvement of residents as stakeholders in protecting the environment, a model conservation strategy must be framed with the local administration and government agencies to protect the environment. The Island group like Thinakara and Parali in Lakshadweep are potential sites to develop as conservation reserves to protect macroalgae, considering their potential for tourism development. The lagoon and beaches of these islands also play a significant role as feeding and breeding grounds for marine turtles. Being ecologically sensitive, these islands can benefit this lagoon's productivity directly and indirectly.

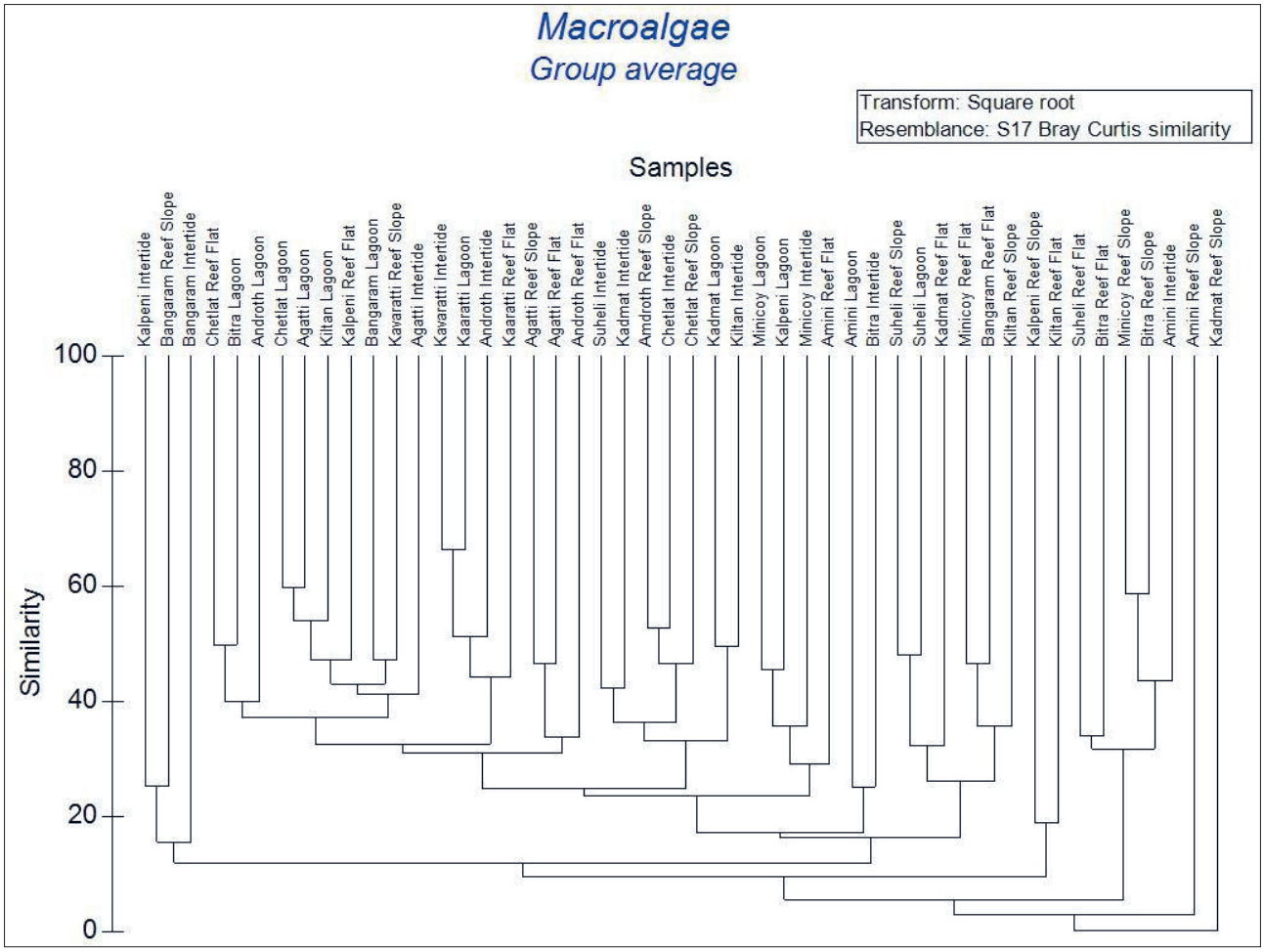

Fig. 4. Dendrogram showing the similarities of Macroalgal assemblages in different biogeographic regions of selected atolls of Lakshadweep Archipelago.

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