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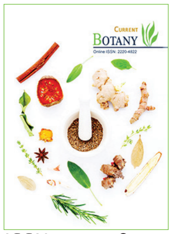

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Diversity, distribution and seasonal variation of seaweeds in Southwest coast of Peninsular India

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ABSTRACT

Six different research locations around the southwest coasts of Tamil Nadu and Kerala were used for the current investigations on the diversity, distribution, and seasonal fluctuation of seaweeds (India). A total of 73 Chlorophyta, Ochrophyta and Rhodophyta were recorded under 23 families and 38 genera. The study site Rasthakaadu (53) was with the maximum number of seaweeds followed by Kanniyakumari (51). Out of six study sites, four study sites (Rasthakaadu, Kanniyakumari, Muttom, Kurumpanai) were dominant with Rhodophyta in contrast to the other two study sites (Vallavilai, Vizhinjam) in which Chlorophyta was dominant. Chlorophyta such as *Chaetomorpha antannina*, *C. indica*, *C. media*, *Ulva fasciata*, *U. lactuca*, brown seaweeds *Sargassum ilicifolium* and red seaweed *Gracilariopsis longissima* were commonly seen in the study area. *Chaetomorpha indica* (Chlorophyceae) was recorded as the most dominant species in season I, whereas *Sargassum ilicifolium* (Phaeophyaceae) was considered as the most dominant seaweed taxon in seasons II and III. The seasonal variation in physicochemical parameters of seawater had much influence on the growth of seaweeds. Comparing the eastern Coromandel Coast of peninsular India to the western Malabar Coast, it has been found from the current study that the eastern Coromandel Coast was rich in seaweed. Moreover, the study shows that the topography and seasonal change of the physicochemical characteristics of seawater at a given site were the key determinants of seaweed richness. Anthropogenic activities, like Nuclear power plants (Koodankulam), sand mining, construction works, dumping of plastics etc., also affected the potential growth of seaweeds thereby reducing the sustainability of the natural resource.

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INTRODUCTION

The marine algae are usually seen on rocky shores, wooden pieces, fishnets, hard solids, etc., and are often subjected to tides and waves. Seaweeds and sea grass meadows help to reduce wave action and protect shores from erosion (Phang *et al*., 2005). The long stretch of Indian Coastal regions like Malabar Coast, Konkan Coast, Coromandel Coast, etc., are rich in seaweeds (Kaliaperumal & Kalimuthu, 1997) with the occurrence of more than 844 species of seaweeds (NAAS, 2003). The second-largest coastline in India is the Coromandel Coastline, which is located in the state of Tamil Nadu (1,076 km long) with an abundance and diversity of marine organisms (Pujiastuti, 2010). The amount of nutrients and bioactive substances varies according to a number of environmental conditions, including water temperature, salinity, and light (Gupta & Abu-Ghannam, 2011) which vary according to the seasons and change in ecological conditions (Lobban *et al*., 1985). Moreover, changes in dissolved nutrients, seawater temperature, and salinity have an impact on the amount of organic and inorganic molecules present (Macler & West, 1987).

Seaweeds are crucial ecological and economic elements of marine ecosystems all over the world. They are the primary producers of food not only for marine organisms but also for human beings. Nowadays seaweeds are also used for medicinal purposes (Muraoka, 2004) due to the production of a panel of bioactive substances (Rajauria & Abu-Ghannam, 2013; Mhadhebi *et al*., 2014; Cho *et al*., 2014; Addico & deGraft-Johnson, 2016; Malathi *et al*., 2018). Around the world, more than 1,50,000 macroalgal species are found in oceans (Benhissoune *et al*., 2001). With the importance of food and medicinal values of seaweeds, several species are cultivated in different countries. Sixty to seventy percent of Indian adolescent girls are suffering from Anemia (Saloojee & Pettifor, 2001; WHO, 2008) which may be treated by some green seaweed like *Ulva reticulata* with higher amount of iron content (Madhurjaya, 2010). Many types of seaweed with higher amounts of iodine are useful for the preparation of drugs and extraction of agar-agar (UNEP, 1998). Some seaweeds are also used as antibiotics with the presence of organic and inorganic chemical compounds (Reid *et al.*, 2013).

Caulerpa racemosa is cultivated as a source of food in Philippines. Some of the seaweeds are regularly harvested by China and Japan for food. According to estimates, sea algae produce eight times as much food as land plants (Yarish & Wamukoya, 1990). The nutritional makeup of macroalgae is thought to vary greatly depending on the species, habitat, growth stage, geographic origin, season, and environmental factors (Marinho-Soriano *et al.*, 2006; Ortiz *et al.*, 2006; Gressler *et al.*, 2010). Concern over how climate change may affect seaweed quantity, distribution, and quality, which will ultimately have an impact on biomass, has been growing globally (Bell *et al.*, 2015).

The Indian government has allotted a budget of about $88.34 million to develop the industry and gives subsidies for seaweed farming (Gomez, 2021). Despite the fact that South India's coastal region is abundant in economically significant seaweeds, there are few reports on their existence. A thorough knowledge on the richness of seaweeds in different regions of the Indian Coast is very important for the sustainable utilization of seaweed resources. The present study has been aimed at examining the diversity and seasonal variation of seaweeds in the southwest Coast, the meeting point of the Malabar Coast and Coromandel Coast, of India along with hydrological parameters.

MATERIAL AND METHODS

Study Area

The study was conducted between November 2018 and October 2019. Six research locations were chosen for the study from two Indian states (Tamil Nadu 5: Kanniyakumari District; Kerala 1: Thiruvananthapuram District). Rasthakaadu (S1), Kanniyakumari (S2), Muttom (S3), Kurumpanai (S4), Vallavilai (S5), and Vizhinjam (S6) in the Trivandrum district of Kerala and the Kanniyakumari district of Tamil Nadu, respectively (Figure 1). Seaweed samples were collected in season I (November to February), season II (March-June), season III (July-October) during the low tide period. For the present study, a one-meter square area was randomly selected in the intertidal zone from every study site. The regular visit was undertaken at a particular time of interval to the selected sampling sites. A random sampling method was followed to collect the seaweeds by hand-picking approach. The seaweed bed was broken up into small pieces, which were then preserved in the seawater-filled bottle. The gathered seaweeds were cleaned in saltwater to get rid of all the dirt and debris before being transported to the lab and preserved in a solution of seawater and formalin (4 percent formalin in seawater). Herbarium specimens were prepared and placed in the Nesamony Memorial Christian College, Marthandam, Department of Botany and Research Center.

Figure 1: Study area (a-b). a) Study area in India and b) south India, c) Rasthakaadu, d) Kanniyakumari, e) Muttom, f) Kurumpanai, g) Vallavilai and h) Vizhinjam

Identification

The taxonomic keys devised by various authors were used to identify the collected seaweeds. (Issac & Issac, 1968; Shrinivasan, 1969, 1973; Moorjani & Simpson 1988; Silva *et al.*, 1996; Cordero, 1997; Desikachary *et al.*, 1998; Krishnamurthy, 2000; Krishnamurthy, 2005; Lobban & N'yeurt, 2006; Huisman, 2010). The abundance and availability of seaweeds were recorded from all the study sites throughout the seasons. The study sites and the collected seaweeds were documented during the field visits by taking photographs using NIKON D60 digital camera. The salinity, temperature and pH value of the seawater were tested throughout the seasons. The temperature was measured using an ordinary mercury thermometer, salinity was determined by a refractometer, and a digital pH metre was used to measure pH. The same day, collected water samples were delivered in a cool box to the lab for nutrient analysis. By using colorimetric techniques, dissolved oxygen (DO), nitrates, phosphate, and silicate were examined (Lobban & N'yeurt, 2006).

RESULTS

General Diversity of Seaweeds in the Present Study Area

A total of 73 different seaweeds (72 species, 1 variety), belonging to 23 families, and 38 genera under the three classes Chlorophyceae, Phaeophyceae and Rhodophyceae were recorded from all six study sites during the study period. Overall, 19 species (8 genera, 6 families) from Chlorophyceae, 22 species (7 genera, 3 families) from Phaeophyceae and 32 taxa (31 species+1 variety, 23 genera, 14 families) from Rhodophyceae were recorded (Table 1, Figure 2a & b), from the present study area. Families such as, Boodleaceae, Bryopsidaceae, Codiaceae (Class Chlorophyceae), Champiaceae, Halymeniaceae, Rodymeniaceae, Liagoraceae, Bangiaceae, Areschongiaceae and Scinaiaceae (Class Rhodophyceae) were monogeneric and monospecific each. Four families namely, Cearamiaceae, Gelidiaceae, Cystocloniaceae and Spyridiaceae (Class Rhodophyceae) were with a single genus and two species each. The family Dictyotaceae of brown algae contained the maximum number of species (10). In the family Rhodomeliaceae of red algae, the maximum number of genera of six were found (Figure 2c).

A total of 19 species (26%) of green seaweeds were gathered over the course of the study period. The highest number (15) of seaweeds was recorded during seasons II and III and the lowest number (12) of species was recorded during season I. *Chaetomorpha*, *Caulerpa*, *Ulva* and *Enteromorpha* were the common green seaweeds recorded in the study area. 22 species (30%) of brown seaweeds were recorded and majority of the species were from study site 1, they include *Sargassum*, *Dictyota*, *Padina*, *Colpomenia*, *Chnoospora*, *Spathoglossum* and *Turbinaria*. The genus *Sargassum* was commonly found throughout the study period. More vegetation and richness of taxa from brown algae were found in season III and the least number of brown seaweeds was recorded from the site 5. Red seaweeds were very high in number in all the study sites with a total of 14 families, 23 genera and 32 species. Within the study area, more vegetation of red seaweeds was occupied in site 1 (Rasthakaadu - 25 species) followed by site 4 (Kurumpanai - 24 species) and site 2 (Kanniyakumari - 23 species (Figure 4). *Gracilariopsis longissima* was the most common species in red algae (Figure 3d & e). Fifty red seaweeds were collected during the II and III seasons (Figure 2d & e).

The current study demonstrates the variation in seaweed richness and diversity in general with reference to the topography (longitude/latitude) of a particular study site (Figure 7a). Thus, Rasthakaadu (53 species) and Kanniyakumari (51 species) on the eastern side of the extreme tip of southern India are rich in seaweeds in contrast to the other four sites (except Kurumpanai - 47 species) on the western side of South India with poor representation of seaweeds (23-36).

The physical features of the Coastal plains are thought to be the cause of the difference in seaweed abundance between India's east and west coasts. Thus, western Malabar Coastal plains have a narrow margin interspersed by hilly terrain in contrast to wide plains with well-developed deltas on the eastern Coromandel Coastal plains. In addition, there is a major change in climate between these two Coastal plains due to the presence of continuous long stretched Western Ghats beside the west Coast in contrast to the fragmented Eastern Ghats beside the east Coast which experiences frequent cyclones.

Seasonal Variations

The number of species and genera varies with season with the maximum number of species (50) during the winter season (July - October) in contrast to the presence of only 23 species during the summer season (March - June). In between the winter and summer seasons, 42 species were recorded (Figure 2d & e). But, the number of genera (23-25) does not vary much during different seasons with the indication that different species of the same genus may be adapted to grow in different seasons as discussed below.

Season I (November to February)

In season I, totally 42 species under 25 genera of seaweeds were recorded with the dominance of red seaweeds (20 species, 16 genera), followed by green seaweeds (12 species, 6 genera) and brown seaweeds (10 species, 3 genera, Figure 2). The red seaweed, *Acanthophora dendroides*, the green seaweed *Chaetomorpha indica* and the brown seaweed *Dictyota dichotoma* were the dominant species.

Season II (March-June)

Among the three families, 23 taxa (18 genera) from Rhodophyceae were recorded from all the sites during the second season (Figure 2e). The red seaweed, *Spiridia hypnoides* was seen as the dominant species. In the meantime *Porphyra suborbiculata*, *Laurencia parvula* and *Champia compressa* were seen as rare taxa. Totally12 brown seaweeds and 15 green seaweeds were recorded. The species *Chaetomorpha media* was seen more extensively. Species such as *Chaetomorpha antannina*, *C. media*, *Ulva fasciata* and *U. lactuca* from Chlorophyceae were commonly seen in all the sites, in contrast to species such as *Chaetomorpha media*, *C. aerea*, *Enteromorpha compressa* and *E. intestinalis* which were found to be the rare species with their occurrence in any one study site. *Sargassum* was seen abundantly in all the selected study sites except Vizhinjam (Kerala). *Sargassum ilicifolium* was noted as the most dominant species in Sites 2, 3 and 4. *Dictyota dichotoma* was also recorded throughout the study area except in the study site Vizhinjam. *Dictyota dichotoma* var. *intricate* of Phaeaphyceae was one of the rarest species which was seen only in study site 1. *Sargassum duplicatum* was the co-dominant taxon in study sites 1-4 but was completely absent in study sites 5 and 6. All the recorded species from brown algae were present in study site 1 itself whereas *Colpomenia peregrina* was the co-dominant species which was present only in study site 1 and absent in all the other sites. Most of the species belonged to the genus Sargassum (5 species), followed by *Padina* and *Dictyota* (3 species each) and only one species from *Colpomenia*.

Table 1: Check list and occurrence of seaweeds in the study area

Scientific name	Study sites					
	S_1	S_2	S_3	S_4	S_5	S_6
Chlorophyceae (19)						
Boodlea composita (Harvey) F. Brand	+	+	-	+	-	-
Bryopsis plumosa (Hudson) C. Agardh	-	-	-	-	-	+
Caulerpa corynephora Montagne	+	+	-	+	+	+
Caulerpa peltata J.V. Lamouroux	+	+	-	+	-	+
Caulerpa racemosa (Forsskal) C. Agardh	+	+	+	+	-	+
Caulerpa scalpelliformis (R. Brown ex Tumer) C.Agardh	-	+	-	+	-	-
Chaetomorpha antennina (Bory) Kützing	+	+	+	+	+	+
Chaetomorpha aerea (Dillwyn) Kutzing	-	-	-	-	+	-
Chaetomorpha indica (Kutzing) (Type from Tranquebar TN)	+	+	+	+	+	+
Chaetomorpha linum (O.F Muller) Kutzing	-	+	-	-	-	-
Chaetomorpha linoides Kutzing	-	-	-	-	+	-
Chaetomorpha media (C.Agardh) Kützing	+	+	+	+	+	+
Codium arabicum Kutzing	+	+	+	+	-	+
Enteromorpha compressa (Linnaeus) Nees	-	-	-	-	+	-
Enteromorpha intestinalis Linnaeus	+	-	-	-	-	+
Ulva fasciata Delile	+	+	+	+	+	+
Ulva intestinalis Linnaeus	-	-	-	-	-	+
Ulva lactuca Linnaeus	+	+	+	+	+	+
Valonia urticularis (Roth) C.Agardh	+	+	+	+	-	-
TOTAL (19)	12	13	8	12	9	12
Phaeophyceae (22)						
Colpomenia peregrina Sauvagaeu	+	-	-	-	-	-
Colpomenia sinuosa (Mertens ex Roth) Derbes & Solier	+	-	-	-	-	-
Chnoospora implexa J. Agardh	-	+	-	-	+	-
Dictyota bartayresiana J.V. Lamouroux	-	+	+	-	-	-
Dictyota dichotoma (Hudson) J.V Lamouroux	+	+	+	+	+	-
Dictyota dichotoma var. intricata (C. Agardh) Greville	+	-	-	-	-	-
Dictyota ceylanica Kutzing (Type from Sri Lanka)	+	+	-	-	-	-
Dictyota ciliolata Sonder ex Kutzing	+	+	+	+	-	-
Padina australis Hauck	+	+	+	+	-	-
Padina commersonii Bory	-	+	-	-	-	-
Padina pavonica (Linnaeus) Thivy	+	+	+	+	-	+
Padina tetrastomatica Hauck	+	+	+	+	-	-
Sargassum cristaefolium (Turner) C. Agardh	-	-	+	-	-	-
Sargassum duplicatum (Turner) C. Agardh	+	+	+	+	-	+
Sargassum johnstonii Stelchell & L. Gardner	-	-	+	-	-	-
Sargassum ilicifollium (Turner) C. Agardh	+	+	+	+	+	+
Sargassum linearifolium (Turner) C. Agardh	+	+	+	+	-	-
Sargassum tenerrimum J. Agardh	+	+	+	+	-	-
Sargassum swartzii C. Agardh	+	+	-	+	-	-
Sargassum wighti Greville	+	+	+	+	-	-
Spathoglossum variabile Figari& De Notaris	+	-	-	-	-	-
Turbinaria conoides (J. Agardh) Kutzing	-	-	-	-	-	+
TOTAL (22)	16	15	13	11	3	4
Rhodophyceae (31+1)						
Acanthophora dendroides Harvey	+	+	+	+	-	+
Amphiroa anceps (Lamark) Decaisne	+	+	-	+	-	+
Amphiroa foliacea J.V. Lamouroux	+	+	-	+	-	-
Ceramium virgatum Roth	+	-	+	-	-	-
Centroceras clavulatum (C. Agardh) Montagne	+	+	-	+	-	-
Champia compressa Harvey	-	-	-	-	-	+
Cheilosporum spectabile Harvey ex Grunow	+	+	-	+	-	-
Gelidiella acerosa (Forsskal) Feldmann & G. Hamel	+	+	-	-	-	-
Gelidiella spinosum (S.G. Gmelin) P.C. Silva	+	+	-	+	-	-
Gracilaria corticata (J. Agardh) J.Agardh	+	+	+	+	-	-
Gracilaria corticata var. *cylindrical* Umamaheshwara Rao	+	-	-	+	-	+
Gracilaria fergusonii J. Agardh	+	+	+	+	-	-
Gracilariopsis longissima (S.G. Gmelin) M. Steentoft.L.M. Irvine &W.F.Farnham	+	+	+	+	+	+
Gracilariopsis megaspora E.Y. Dawson	+	+	-	+	-	--
Grateloupia indica Borgesen	-	-	-	+	-	-
Halopeltis australis (J. Agardh) G. W Saunders	+	-	+	-	-	-
Hypnea musciformis (Wulfen) J.V. Lamouroux	+	-	+	-	-	-
Hypnea valentiae (Turner) Montagne	+	+	+	+	-	-

(Contd...)

Table 1: *(Continued)*

Scientific name	Study sites					
	S_1	S_2	S_3	S_4	S_5	S_6
Jania rubens (Linnaeus) J. V Lamouroux	+	+	+	+	-	-
Jania squamata (Linnaeus) J.H.kim, Guiry&H.G.choi	+	+	+	+	-	-
Laurencia parvula Borgesen	-	+	-	-	-	+
Type locality: Krusadi Island, near Pamban, Tamil Nadu, India (Silva *et al.,* 1996).						
Liagora albicans J. V Lamouroux	-	+	-	+	-	-
Osmundea pedicularioides (Borgesen) G. Furnari, Serio & Cormaci Type locality: Dwarka, Gujarat, India	+	+	+	+	-	-
Palisada flagellifera (J.Agardh) K. W. Nam	-	-	-	+	-	-
Palisada perforata (Bory) K.W.Nam	+	+	+	+	-	-
Palmaria palmata (Linnaeus) F.Weber & D.Mohr	+	+	+	+	-	-
Polysiphonia variegata (C. Agardh) Zanardini	+	+	-	+	-	+
Porphyra suborbiculata Kjellman	-	+	-	-	-	-
Sarconema filiforme (Sonder) Kylin	+	-	-	+	-	-
Scinaia carnosa (Kutzing) J. Agardh	-	+	-	-	-	-
Spyridia filamentosa (Wulfen) Harvey	+	+	+	+	-	-
Spyridia hypnoides (Bory)Papenfuss	+	+	+	+	-	-
TOTAL (31 sp. +1 var.)	25	23	15	24	1	7
TOTAL S1-12+16+25=53, S2-13+15+23=51, S3-08+13+15=36, S4-12+11+24=47, S5 09+03+01=13, S6-12+04+07=23 (GRAND TOTAL 72 sp. + 1 var.)						

S_1- Rasthacaud; S_2- Kanyakumari; S_3- Muttom; S_4- Kurumpanai; S_5-Vallavilai; S_6- Vizhinjam; +-Present; Absent.

In general, red algae (Rhodophyceae (23)) were the most dominant group when compared to Chlorophyceae and Phaeophyceae, with the presence of the maximum number of species under 18 genera throughout the seasons in study site 2. The abundance of Rhodophyceaen members was very high during season II when compared to season I, because of the extension of their distribution all over the study area. *Gracilariopsis longissima* was the dominant species which was common throughout the study area in season II. *Champia compressa* (S6) and *Porphyra suborbiculata* (S2) were considered as a subdominant species which had been seen only in one site. *Laurencia parvula* was the rarest species from Rhodophyceae which was recorded from a single site, Kanniyakumari (S2).

Season III (July - October)

A total of 50 seaweed species under24 genera representing Chlorophyceae (7 genera, 15 species), Rhodophyceae (10 genera, 14 species) and Phaeophyceae (7 genera, 21 species) were recorded throughout the study area during season III with the dominance of Chlorophyceae followed by Rhodophyceae. The highest number (10) of genera was recorded from Rhodophyceae in season III (Figure 2e). *Ulva fasciata* and *U. lactuca* were comparatively more abundant than other species of Chlorophyceae in which *Chaetomorpha linum* was the rarest species found only in Site 2. Similarly, in Phaeophyceae, *Sargassum ilicifolium* was the common species and *Padina commersonii*, *Spathaglossum variable* and *Turbinaria conoides* were the rare species in season III. During this season, *Osmundea pedicularioides* was the most common species of Rhodophyceae in which *Gracilaria corticata var. cylindrica* was the rare species.

A maximum number (32 species under 17 genera) of seaweeds representing Chlorophyceae (3 genera, 5 species), Phaeophyceae (5 genera, 15 species) and Rhodophyceae (9genera, 12 species) were recorded from Site 1 followed by Site 4 with 24 species under 19 genera (Chlorophyceae 10, Rhodophyceae - 11 species, Phaeophyceae - 3).

During season III, 8 green seaweeds (5 genera), 4 brown seaweeds (3 genera) and 7 red seaweeds (7 genera) were recorded. Site 3 was with 24 species under 11 genera (Chlorophyceae: 2 genera/4 species, Phaeophyceae: 4 genera/13 species and Rhodophyceae: 5 genera/7 species). The lowest number (9) of species was recorded from study site 5 in season III. Among them 7 species fewer than 3 genera are from Chlorophyceae. Phaeophyceae and Rhodophyceae are represented by single species each in site 5 (Figure 2e).

The richness and vegetation of seaweed species from Chlorophyceae were very low during season III compared to season II but higher than season I. 15 species (8 genera) were found from this family throughout the season. The highest number (11 species, 6 genera) of species and genera from green algae was recorded from study site 2. *Ulva fasciata* was the most dominant species from Chlorophyceae. *Enteromorpha compressa* and *Chaetomorpha linum* were the rare species of green seaweeds with their occurrence in single site only. *Boodlea composita*, *Bryopsis pulmosa*, *Chaetomorpha linoides* and *C. linum* of Chlorophyceae emerged newly in season III and they were absent in season II. In the same way, some species recorded during season II disappeared during season III.

Brown seaweeds were found to grow there more easily in Season III with a record of 21 species under 7 genera throughout the area. *Padina commersonii*, *Spathaglossum variable* and *Turbinaria conoides* were the rare species from the brown algae found only in study sites 2, 1 and 6 respectively. Brown seaweeds such as *Chnoospora implexa*, *Colpomenia sinuosa*, *Dictyota bartagresiana*, *D. ceylanica*, *Padina commersonii*, *Sargassum cristaefolium*, *S. johnstonii*, *Spathaglossum variable* and

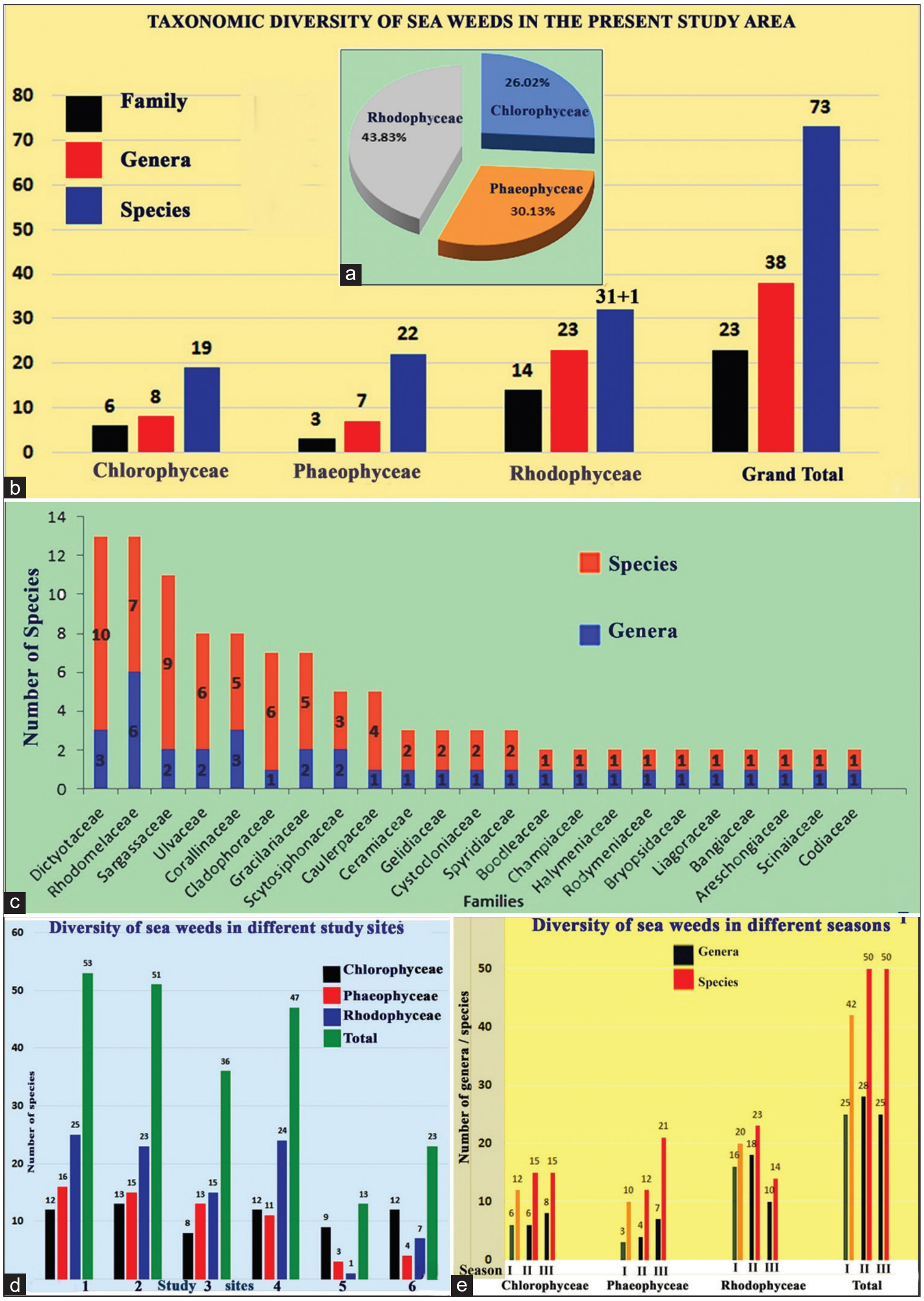

Figure 2: a-b) Diversity of family, genera and species in different classes (Chlorophyceae, Pheaophyceae and Rhodophyceae) of seaweeds, c) Diversity of genera and species in different families, d-e) Diversity of seaweeds in different study sites (d) and seasons (e).

Turbinaria conoides were found to be newly emerged seaweeds during season III and they were absent in season I and II. The season III was more suitable for the growth of Phaeophyceae. The weather condition, temperature and physicochemical parameters in the seawater during season III might have enhanced the potential growth of brown seaweeds.

Unexpectedly, season III was found to be unfavourable for the growth of red seaweeds with a record of only 14 species (10 genera) throughout the study area. The majority of red seaweeds from season III were from study site 4 (Figure 2d). *Gracilariopsis longissima* was the most common species in season III. *Palisade flagellifera*, *Gracilaria corticata* and *G. corticata var. cylindrica* were considered rare taxa. *Palisade flagellifera* was the only one newly emerged species red algae during season III. Comparatively more species were found to have disappeared during this unfavorable season.

It has been noted in the current investigation that different kinds of seaweeds of the same or different genus/genera appear and disappear in different seasons with the indication for the

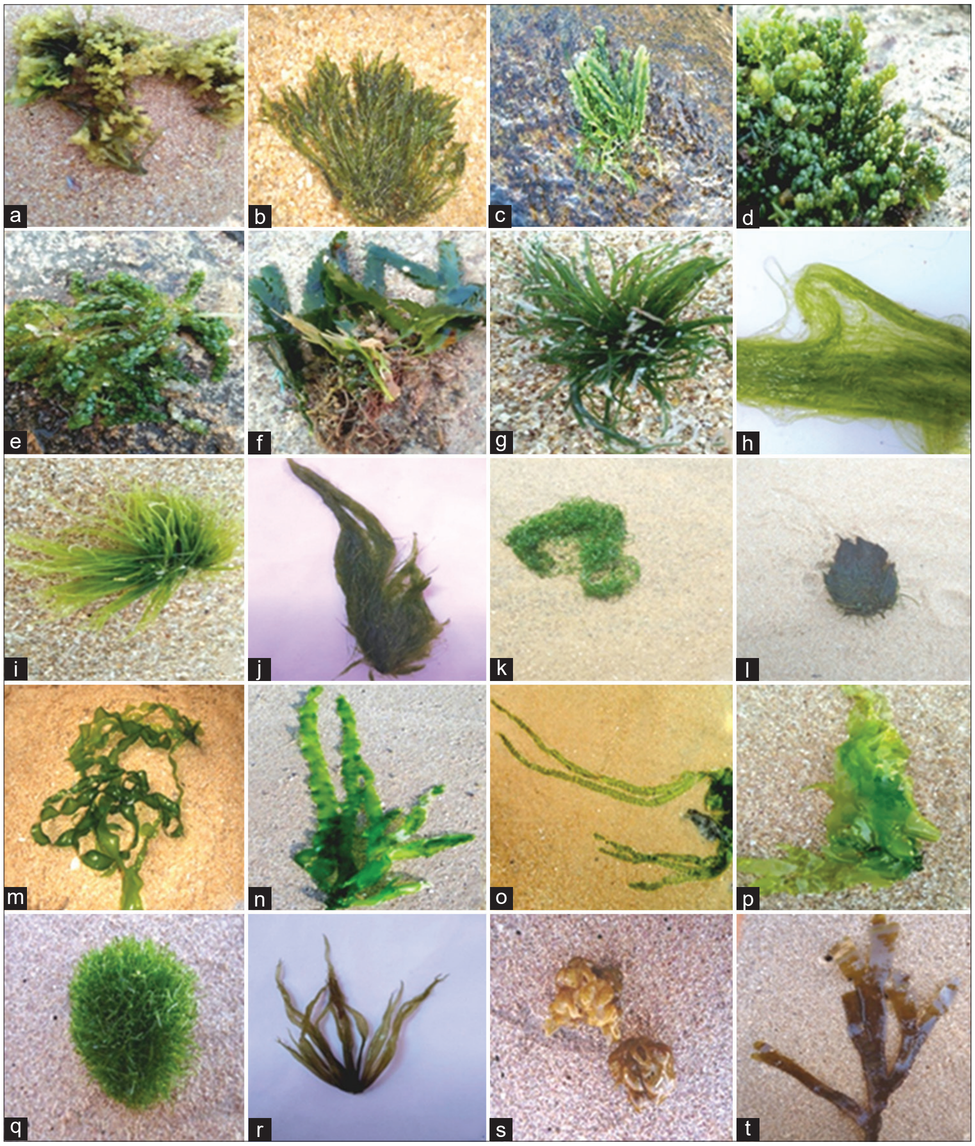

Figure 3: Seaweeds from the present study area. a) *Boodlea composite,* b) *Bryopsis pulmosa,* c) *Caulerpa corynephora,* d) *C. racemosa,* e) *C. peltata,* f) *C. scalpelliformis,* g) *Chaetomorpha antannina,* h) *C. indica,* i) *C. media,* j) *C. linoides,* k) *C. linum,* l) *Codium arabicum,* m) *Enteromorpha intestinalis,* n) *Ulva fasciata,* o) *U. intestinalis,* p) *U. lactuca,* q) *Valonia urticularis*, r) *Enteromorpha compressa,* s) *Colpomenia peregrine* and t) *Dictyota dichotoma var. intricate.*

suitability of climatic conditions and adaptability of particular species. Thus, seaweeds may be utilized as potential ecological indicators as recently reviewed by D'Archino and Piazzi (2021).

Physicochemical Parameters of Sea Water

During the study period, the ranges of atmospheric temperature/surface water temperature were 30-33 ºC/28-30 ºC, 31-34 ºC/29-32 ºC and 33-36 ºC/30-33 ºC during Season I, II and III respectively. Thus, both atmospheric and surface water temperatures has gradually increased from season I (November to February) to season III (July-October). The salinity of seawater ranges from 33.76 ppt (Kanniyakumari) to 37.81 ppt (Vizhinjam).The phosphate content of seawater ranges from 0.2 mg/L in Muttom to 1.0 mg/L in Kurumpanai. The Nitrate content of water is minimum (5 mg/L) in Vallavilai and maximum (100 mg/L) in Muttom. Dissolved oxygen is minimum (6.4 mg/L) in Muttom and maximum (6.4 mg/L) in Kurumpanai (Figure 5). Seawater from Kanniyakumari is with minimum (3.9 mg/L) amount of silicate, in contrast to seawater from Kurumpanai with maximum (5.2 mg/L) amount of silicate (Figure 6).

Seaweeds are sensitive to the atmospheric and water temperature and thus they show significant variation in different seasons. Thus, in total, maximum generic and species diversity has been observed in the season II (March-June, 50/28) followed by season III (July-October, 50/25) with the minimum diversity during season I (November - February, 42/25). From the present study, it is observed that seaweeds are very sensitive to the phosphate content of marine water. It is uniformly maximum during the first season and minimum during the third season in all six

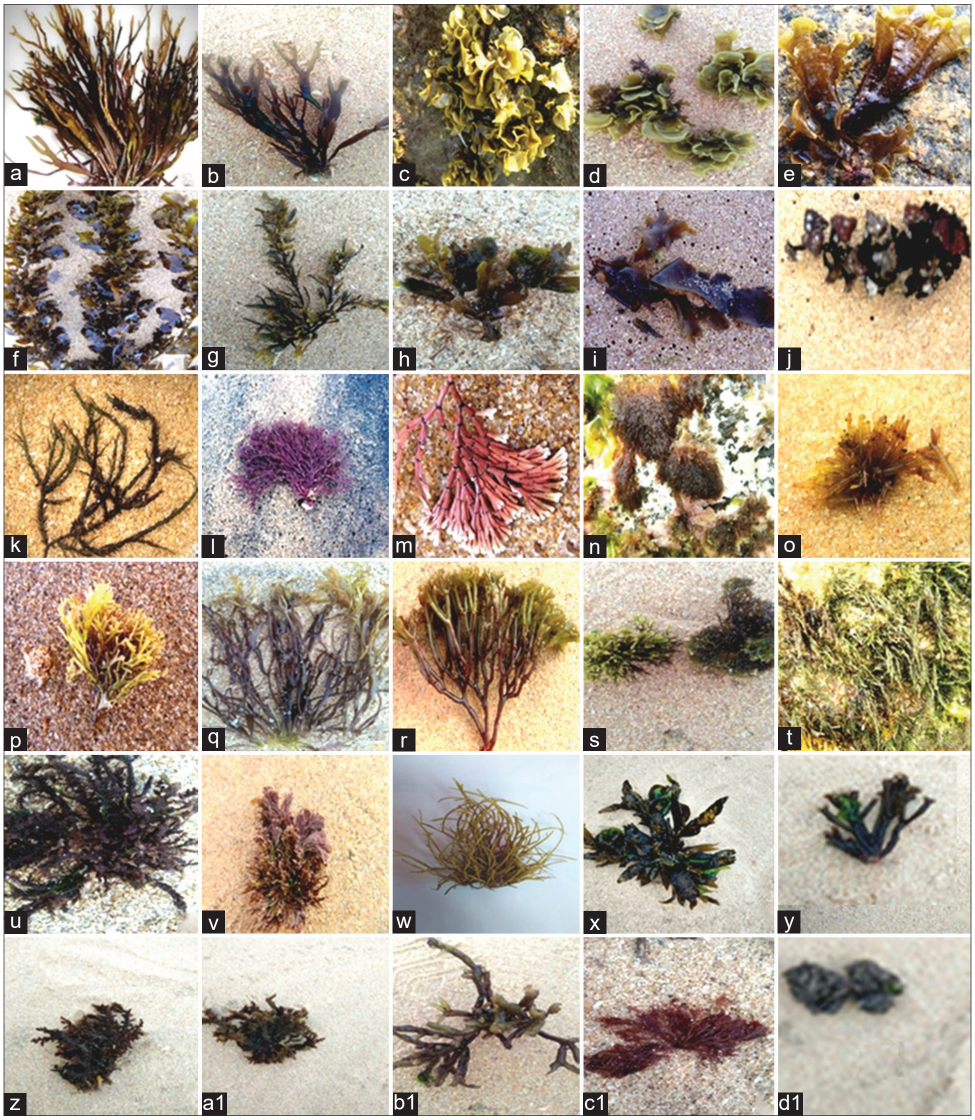

Figure 4: Seaweeds from the present study area. a) *Dictyota Ciliolate,* b) *D. dichotoma,* c) *Padina australis,* d) *P. pavonica,* e) *P. tetrastomatica,* f) *Sargassum duplicatum,* g) *S. tenerrimum,* h) *S. wightii,* i) *Spathoglossum variable,* j) *Turbinaria conoides,* k) *Acanthophora dendroides,* l) *Amphiroa anceps,* m) *A. foliaceae,* n) *Ceramium virgatum,* o) *Champia compressa,* p) *Gracilaria corticata var. cylindrical,* q) *G. corticata,* r) *G. fergusonii,* s) *Gracilariopsis longissima,* t) *Hypnea musciformis,* u) *H. valentiae,* v) *Jania squamata,* w) *G. megaspore,* x) *Grateloupia indica,* y) *Halopeltis australis,* z) *Spiridia hypnoides,* a1) *S. filamentosa,* b1) *Scinaia carnosa,* c1) *Sarconema filiforme* and d1) *Jania rubens*

study sites (Figure 6). Maximum range (0.7-1.0 mg/L) has been observed in study site 6 (Vizhinjam with 23 seaweeds) followed (0.69-1.0 mg/L) by study site 4 (Karumpanai with 47 seaweeds). The medium range of phosphate concentration 0.45-0.75 mg/L in study site 1 (Rasthakaadu (53)) with the maximum number of seaweeds is considered as the optimum concentration of phosphate for the growth of seaweeds followed by study site 2 (Kanniyakumari - 51 seaweeds) with the range 0.31-0.5 mg/L. The higher range (0.7-1.0 mg/L) of phosphate content in study site 6 (Vizhinjam (23)) with lower number of seaweeds is not favourable for the growth of seaweeds. The present study proves that 0.45-0.75 is the optimum range for normal growth of seaweeds in the South Indian Coast.

In the same way, the silicate content was also uniformly maximum during the first season and minimum during the third season in all the six study sites (Figure 6). Both minimum range (2.3-3.9 mg/L) and maximum (2.1-5.2 mg/L) range of silicate content in the study sites 5 (Vallavilai) and 6 (Vizhinjam) respectively, are unfavourable for the growth of seaweeds with the indication of the presence of less number of seaweeds 13 and 23.The medium ranges 2.5-4.1 and 1.7-3.9 mg/L in the study sites 1 (Rasthakaadu) and 2 (Kanniyakumari) are more favourable for the growth of the seaweeds with the occurrence of maximum number (53, 51) of seaweeds.

As far as the nitrate content of seawater for the present study sites is concerned, there was an irregularity with the presence of a minimum range 0.45-5.0 mg/L in the study sites 1 (Rasthakaadu) and 2 (Kanniyakumari) with the maximum number of sea weeds 53 and 51 respectively in contrast to the maximum range 20-100 mg/L in the study sites 3 (Muttom) and 4 (Kurumpanai)

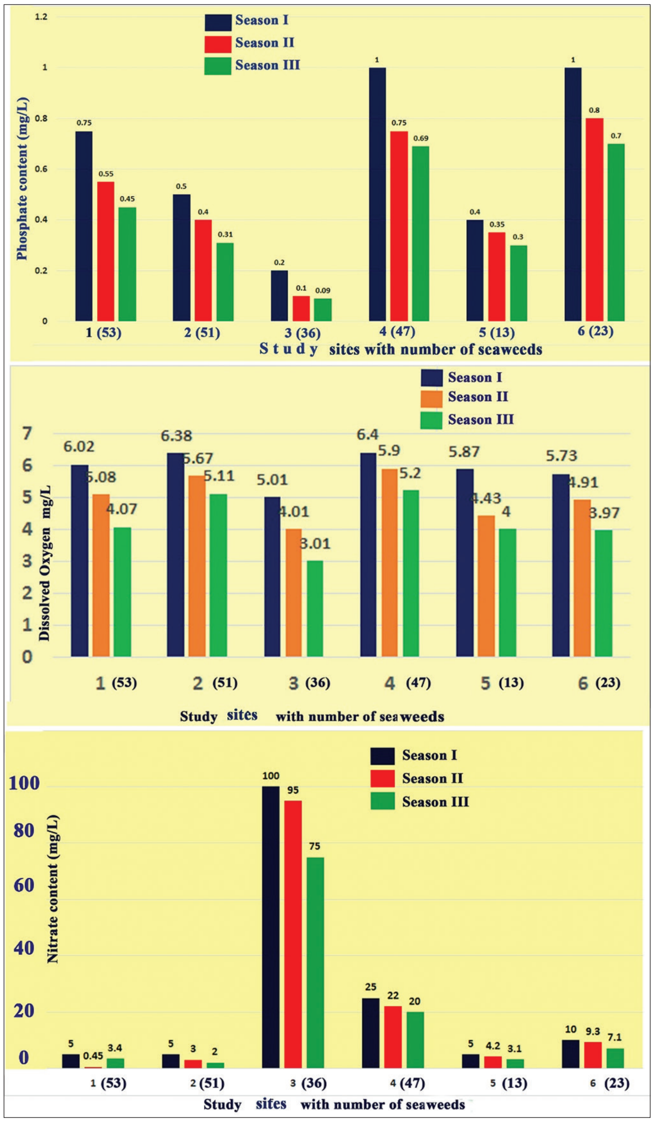

Figure 5: Influence of phosphate, dissolved oxygen and nitrate in sea water, on the diversity of seaweeds in different study sites and seasons

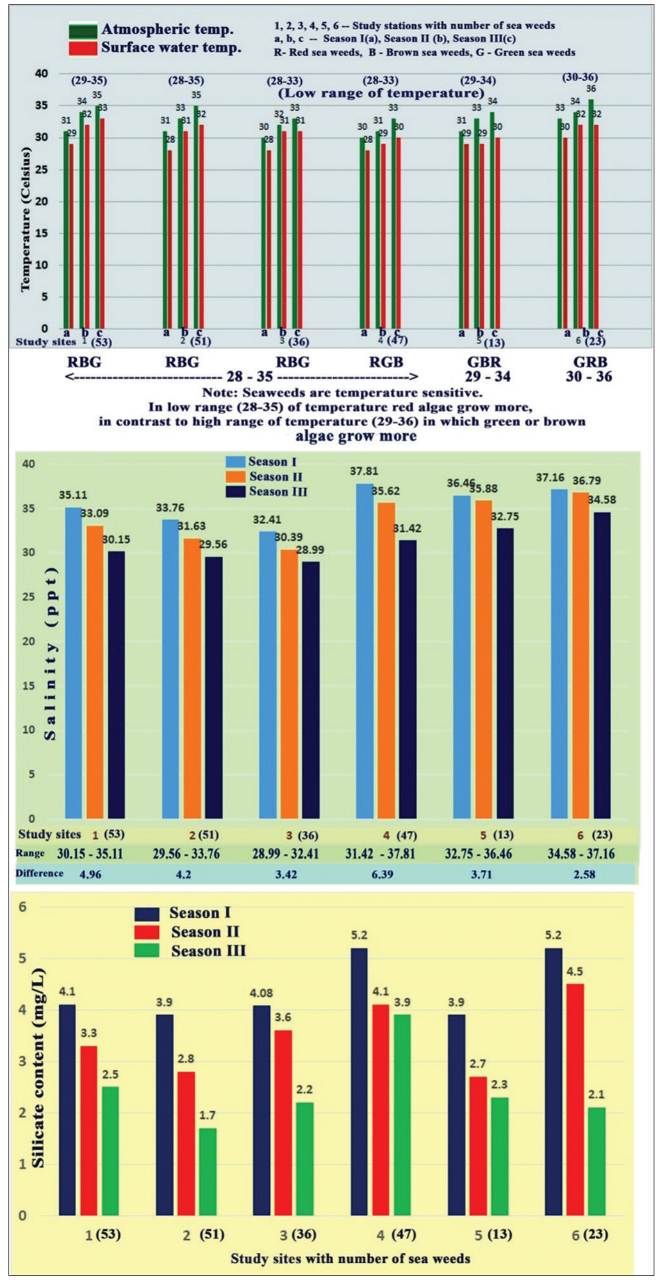

Figure 6: Influence of temperature, salinity and silicate in sea water, on the diversity of seaweeds in different study sites and seasons

with the moderate number (36 and 47) seaweeds respectively. The occurrence of minimum number of the seaweeds 13 and 23 in the study sites 5 (Vallavilai) and 6 (Vizhinjam) respectively, with a low range of nitrate content 3.1-10 mg/L may be due to some other physicochemical and/or topographical factors.

Additionally, dissolved oxygen is crucial for the growth and diversity of seaweeds. Dissolved oxygen is uniformly maximum during the first season and minimum during the third season in all six study sites. The range 4.07-6.38 mg/L seems to be optimum for the growth of seaweeds as prevailed in the seaweed rich study sites 1 (Rasthakaadu - 53 seaweeds) and 2 (Kanniyakumari - 51 seaweeds) in contrast to 3.97-6.4 mg/L range in other four sites with 13-47 seaweed species (Figure 6).

When the seaweed richness is compared with different study sites, as discussed above the west Coast is poorer than the Indian peninsula's east coast. Thus, the topography is the main reason for the poor representation of seaweeds in the study sites 5 (Vallavilai - 13 species) and 6 (Vizhinjam - 23 species) which are without much fluctuation in physicochemical parameters. But, the difference in the richness of seaweeds in the other four study sites, which lies more or less in a similar topographic area, mostly pertains to variation in the physicochemical parameters of seawater. For any individual organism or group of living organisms, uniform, constant and optimum environmental factors are important for their survival without much fluctuation during the annual seasons. It is well known that tropical areas with less fluctuation of climatic factors are rich in biodiversity in contrast to temperate areas with high fluctuation of climatic factors. When the fluctuation pattern of physicochemical parameters is compared, there is great variation

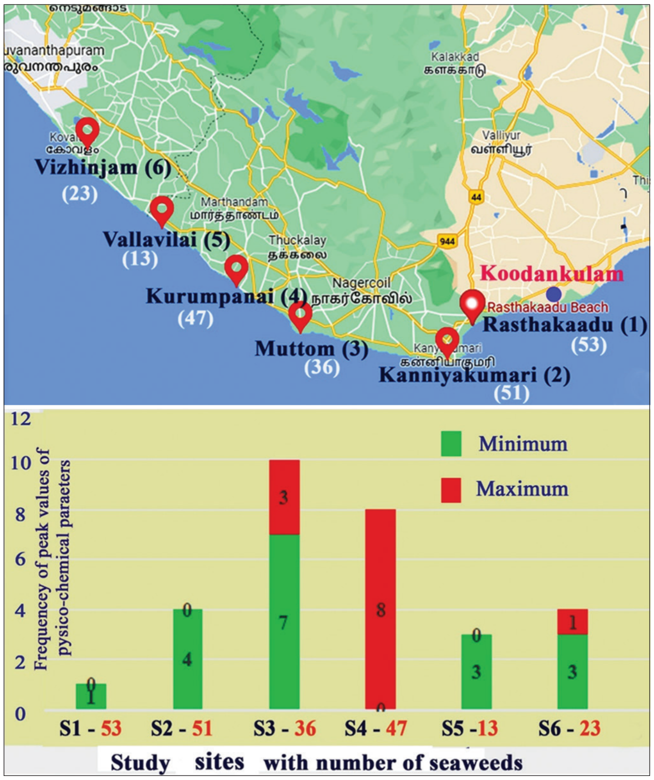

Figure 7: Influence of overall fluctuation of physico-chemical parameters on the diversity of seaweeds in different study sites

among different study sites (Figure 7b). Thus, the seaweed rich (53 species) study site 1, Rasthakaadu, is more or less within the narrow range of fluctuation with only one minimum value (minimum salinity during season III) in contrast to seaweed poor site 4 (47 species), Kurumpanai and site 3 (36 species), Muttom which are with high fluctuation in several physicochemical parameters. Thus, out of 30 peak values (minimum/maximum) for five parameters during three different seasons, site 4 Kurumpanai (47 species) is with 4, 1 and 3 maximum values (Totally 8 peak values) during season I, II and III respectively in contrast to the site 3, Muttom (36 species) with 2, 3, 2 minimum values during season I, II and III respectively and one maximum value in each of the three seasons (Totally 10 peak values). From the present study, it is also evidenced that the study site with more minimum values of physicochemical parameters has more impact on the growth of seaweeds when compared to the number of maximum values. Thus, study site 3 (Muttom) with 7 minimum values and 3 maximum values shows a drastic decline in the number (36) of seaweeds when compared to site 4 (Kurumpanai - 47 seaweeds) with eight maximum values without any minimum value. It is remarkable to note that in the study site Muttom, phosphate and dissolved oxygen are with minimum values in all three seasons with the indication that nutrient deficiency has more impact on seaweed growth when compared to the presence of excess amount (Figures 6 & 7).

DISCUSSION

The present study proved that among the four regions of Tamil Nadu, i.e., Kanniyakumari, Tirunelveli, Thoothukudi and Ramanathapuram, the northernmost region Ramanathapuram harboured the highest number (115 out of 156) of seaweeds followed by Tirunelveli region (93 species), Kanniyakumari and Thoothukudi regions, each with 90 and 86 species respectively (Paul, 2011). Thus, the present study along with the previous study showed that Seaweed diversity on South India's east coast rises from south to north, in contrast to the West Coast where the number of seaweeds decreases drastically from South to North. The present study was carried out to enlist the seaweed diversity of the western coasts of the southern most tiny districts of Kanniyakumari and Thiruvanathapuram. There were only 73 species of seaweeds in the entire Coastal region of Maharashtra (Waghmode, 2017). Almost the same number (74) of seaweeds had been reported from the Coastal region of Goa, the northernmost part of the West Coast of Peninsular India (Dhargalkar, 1981; Agadi, 1986). Out of 186 sites, along the entire (nearly 580 kms) Coastline of Kerala, seaweed growth had been observed only in 53 sites (Krishnamurthy *et al*., 1986) with the occurrence of 35 seaweed species (green algae 245.94 tons, Red algae 91.63 tons and brown algae 18.11 tons). Interestingly, in the present study, 73 seaweed species have been recorded along a short stretch of just 75 km on the southwest coast of southern India. Surprisingly, within a 150 km stretch of East Coromandel Coast of Tamil Nadu, just opposite to seaweed poor Malabar Coast, 156 species (64 genera) of seaweeds had been recorded (Paul, 2011). It is important to mention that both seaweeds and vascular plants are rich in South India which lies both in the vertical longitudinal and horizontal latitudinal plant diversity rich zones of India (Behera & Roy, 2019). Almost all the species are widely distributed around the globe. While long-distance seaweed distribution does occur, it is the exception rather than the rule. If this were the norm, the oceans and both hemispheres' seaweed floras would exhibit identical latitudinal gradients in species composition. But this is not the case (van den Hoek, 1987).

According to Kaliaperumal (2017) there are 871 different types of seaweed found in Indian waters. The regions of Gujarat with the longest (1600 km) stretch of Coastline harbor the highest seaweed diversity (Ganesan *et al*., 2019) with 198 species, of which 109 species from 62 genera, 54 species from 23 genera, and 35 species from 16 genera are members of the Rhodophyta, Chlorophyta, and Phaeophyta, respectively (Jha *et al*., 2009). Thus, red seaweeds are dominant, followed by green seaweeds and brown seaweeds. A recent investigation found 282 species, 146 of which belonged to the phylum Rhodophyta, 80 to the phylum Chlorophyta, and 56 to the phylum Ochrophyta (Ganesan *et al*., 2019). Jha *et al*. (2009) and Pereira and Almeida (2014) reported 39 seaweeds as new records for Goa Coast. Yadav *et al*. (2018) reported two red seaweeds, *Catenella impudica* (Mont.) J. Agardh and *Meristotheca papulosa* (Mont.) J. Agardh (Order Gigartinales), have been discovered for the first time from the coast of Kerala. The present study along with previous studies on seaweeds from the Indian coast show that red seaweeds are dominant uniformly in most of the areas followed by brown or green seaweeds. It may be due to the tolerance of red seaweeds in wide environmental conditions as proved by Yadav *et al*. (2018) and Luning (1984) and the difference in the degree of tolerance of different groups of seaweeds may be attributed to various physiological mechanisms with the presence of different kinds of pigments, antioxidant enzymes and osmolyte accumulation (Khan *et al*., 2015).

The variety, abundance, and species composition of seaweeds commonly depend upon different types of physical, chemical and environmental characteristics (Romdoni *et al*., 2018) and Coastal water is suitable for the growth of seaweeds (Trono, 1997). A total of 73 seaweeds were documented, collected, and identified in the current study, from the low tide zones of South West Coast of Peninsular India (Tamil Nadu, Kerela). Previous studies indicate that wherever the oxygen level is high, the seaweeds were abundantly seen (Trono, 1997). The seasons II and III had the most seaweed species documented, which may be a result of the environment's physical and chemical influences. The present observation is closely correlated with the previous work (Nybakken, 1992).

Numerous environmental parameters, including water temperature, salinity, and nutrients, are linked to variations in seaweed richness, dispersion, and abundance (Dawes, 1998). The synthesis of nutrients in seaweeds can be influenced by seasonal variations in ecological conditions (Lobban *et al*., 1985). During the course of the study, it was discovered that the physicochemical characteristics of seawater, including temperature, pH, salinity, dissolved oxygen, nitrate, silicate, and phosphate content, vary from season to season. This finding may explain the seasonal variation in seaweeds in the study area. The current study is almost in agreement with Barot's findings (Barot *et al*., 2015). The makeup of the macroalgal flora is influenced by the amount of nutrients present in the water. *Ulva* and *Chaetomorpha*, two green macroalgae with high abundances, are typically indicators of nutrient enrichment brought on by runoff from sewage and agricultural fertilizers (Coppejans *et al*., 1997).

Of the 73 seaweeds recorded, 41 seaweeds were collected from season I and50 seaweeds were collected each from season II and III. Studies on the west coast of the Gulf of Mannar showed that environmental parameters are related to the number of species or individuals (Josephine *et al*., 2013). The Physiochemical parameters were found to be a vital role in the potential growth of seaweeds in the study area of season II (postmonsoon) and 3 (summer) particularly for Phaeophyceae and Rhodophyceae. According to Blanckaert *et al*. (2004) and Saikia *et al*. (2012) physical and chemical parameters such as water, sunlight and nutrients play a vital role of ecological efficiency. Throughout the study period Rhodophyceae was dominant in season I and II, but season III was highly dominated by Phaeophyceae compared to season I and II. *Sargassum ilicifolium* from Phaeophyceae was the most dominant species in season II, whereas *Ulva fasciata* from Chlorophyceae was the most dominant species in season III. In contrast, the green alga *Enteromorpha compressa* and the red alga *Laurencia parvula*were the rarest species in season II during the intertidal period. Interestingly, seaweeds such as *Caulerpa corynephora* and *Chaetomorpha aerea* from Chlorophyceae, *Amphiroa foliaceae*, *Cheilosporum spectabilis*, *Gelidiella acerosa*, *Gelidium spinosum*, *Gracilariopsis megaspora* and *Laurencia parvula* from Rhodophyceae were found to grow during season II only and they were not recorded from season I and III.

The presence of intertidal rocky reefs may contribute to the abundance of seaweed in the waters of the Muttom Coast (Satheesh & Wesley, 2012). Compared to the other sites, the diversity and vegetation of seaweeds were very low in the study site Vallavilai due to the fact that the government had deployed stones on sea shores to prevent the huge waves in higher tidal period and to prevent seashore soil erosion. During the present study, a small number of seaweeds occupying in the deployed stones and wooden pieces were recorded.

The activity of marine organisms is influenced by the seasonal changes and changes in the parameters (Krishnan & Dhar, 2021). Comparatively the growth of marine macroalgae decreased in recent years in study site 6 (Vizhinjam-Kerala) due to the construction work connecting with a new international port, sand mining, etc. Anthropogenic activities around the environment adversely affect the growth of marine macroalgae which was very high in site 6 compared to other sites. The diversity index of seaweeds were higher in study sites 1 (Rasthakaadu) and 2 (Kanniyakumari). The current study clearly shows that in all the sites, the pH levels fall within an ideal range for seaweed growth because of low tide (Trono, 1997), various other physicochemical parameters (Romdoni *et al*., 2018), temperature (Sumich, 1992) and other environmental factors. Marine macroalgae can grow optimally in the pH range of 8.12 to 9.01 (Desikachary *et al*., 1998). The current study covers a knowledge gap on the variety of seaweeds along Kerala's and Tamil Nadu's west coast. (Site1 to Site6): S_1 (08°07.928'N; 077°34.329'E); S_2 (08°04.746'N;077°32. 992'E); S_3 (08° 07'.496" N; 077°18.870 E); S_4 (08°11,434'N; 077° 13,675'E); S_5 (08°16'31.94" N; 77°06'30.88" E) and S_6(08°22'45''N; 76°59'29" E) by providing, basic data from biogeographical studies. The current study may also serve as a fresh baseline record for further bio-monitoring investigations in these study locations. On the west coast of peninsular India, additional systematic studies on the seaweed resources may yield helpful information for the preservation and usage of marine macroalgal resources.

The degradation of coastal zones and resources in India is caused by anthropogenic factors such as population pressure, mangrove destruction, wastewater disposal, solid waste management, coastal building, natural catastrophes, ports, coastal erosion, tourism, power plants, coastal mining, etc. (Vivekanandan *et al*., 2003). It is interesting to note that the majority of common red seaweeds of industrial importance, such as *Hydropuntia edulis* (also known as *Gracilaria edulis*) and *Gelidiella acerosa*, have locally disappeared from some of the islands in the Gulf of Mannar as a result of unrestricted and unsustainable harvesting, whereas their natural resources were in abundant supply just a few decades ago (Rao & Chaugule, 2006). Without making prior conservation measures for south Indian seaweeds, many seaweeds may prone to extinct in the south Indian sea coast, particularly due to the presence of the nuclear power plant in Koodankulam, several anthropogenic activities and natural disasters like Tsunami and cyclones due to climate change.

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CONFLICT OF INTEREST

There is no conflict of interest.

AUTHORS' CONTRIBUTION

All authors contributed equally to the collection of seaweeds data and writing of the manuscript.

REFERENCES

Addico, G. N. D., & deGraft-Johnson, K. A. A. (2016). Preliminary investigation into the chemical composition of the invasive brown seaweed *Sargassum* along the west Coast of Ghana. *African Journal of Biotechnology, 15*(39), 2184-2191. https://doi.org/10.5897/AJB2015.15177

Agadi, V. V. (1986). *Marine algal studies of the central west Coast of India*. Doctoral Dissertation, University of Karnataka.

Barot, M., Kumar, J. I. N., & Kumar, R. N. (2015). Seaweed species diversity in relation to Hydro chemical characters of Okha Coast. *International Journal of Current Research and Review, 8*(3), 16-28.

Behera, M. D., & Roy, P. S. (2019). Pattern of distribution of angiosperm plant richness along latitudinal and longitudinal gradients of India. *Biodiversity and Conservation, 28,* 2035-2048. https://doi.org/10.1007/s10531-019-01772-1

Bell, T. W., Cavanaugh, K. C., Reed, D. C., & Siegel, D. A. (2015). Geographical variability in the controls of giant Kelp biomass dynamics. *Journal of Biogeography*, *42*(10), 2010-2021. https://doi.org/10.1111/jbi.12550

Benhissoune, S., Boudouresque, C.-F., & Verlaque, M. (2001). Checklist of Marine seaweeds of the Mediterranean and Atlantic Coasts of Morocco. I. Chlorophyceae Wille *s. l. Botanica Marina, 44*(2), 171-182. https://doi.org/10.1515/BOT.2001.023

Blanckaert, I., Swennen, R. L., Flores, M. P., Lopez, R. R., & Saade, R. L. (2004). Floristic composition, plant uses and management practices in homegarden of San Rafael Coxcatlan, Valley of Tehuacan-Cuicatlan, Mexico. *Journal of Arid Environments, 57*(2), 179-202. https://doi.org/10.1016/S0140-1963(03)00100-9

Cho, M., Park, G.-M., Kim, S.-N., Amna, T., Lee, S., & Shin, W.-S. (2014). *Glioblastoma*-Specific anticancer activity of pheophorbide a from the edible red seaweed *Grateloupia elliptica*. *Journal of Microbiology and Biotechnology, 24*(3), 346-353. https://doi.org/10.4014/jmb.1308.08090

Coppejans, E., Richmond, M. D., de Clerk, O., & Rabesandratana, R. (1997). Marine macroalgae: seaweeds. In M. D. Richmond (Eds.), *A Guide to the Seashores of eastern Africa and the Western Indian Ocean Islands* (pp. 70-95) SAREC, USA: SIDA/Department for Research Coperation.

Cordero, J. R. (1997). Studies on Philippine marine red algae. *Marine Biological Laboratory, 4,* 1-258.

D'Archino, R., & Piazzi, L. (2021). Macroalgal assemblages as indicators of the ecological status of marine coastal systems: A review. *Ecological Indicators, 129*, 107835. https://doi.org/10.1016/j.ecolind.2021.107835

Dawes, C. J. (1998). Marine Botany. (2nd ed.). New York, US: John Wiley & Sons, Inc.

Desikachary, T. V., Krishnamurthy, V., & Balakrishnan, M. S. (1998). *Rhodophyta* (Vol. 2) Chennai, India: Madras Science Foundation.

Dhargalkar, V. K. (1981). *Studies on marine algae of the Goa Coast.* Doctoral Dissertation, Bombay University.

Ganesan, M., Trivedi, N., Gupta, V., Madhav, S. V., Reddy, C. R., & Levine, I. A. (2019). Seaweed resources in India – current status of diversity and cultivation: Prospects and challenges. *Botanica Marina, 62*(5), 463-482. https://doi.org/10.1515/bot-2018-0056

Gomez, E. J. (2021). *PH, India eye $12-B seaweed market*. Retrieved from https://www.manilatimes.net/2021/05/30/business/sunday-business-it/ph-india-eye-12-b-seaweed-market/1801149

Gressler, V., Yokoya, N. S., Fujii, M. T., Colepicolo, P., Filho, J. M., Torres, R. P., & Pinto, E. (2010). Lipid, fatty acid, Protein, and aminoacid in four Brazilia red algae. *Food Chemistry, 120*(2), 585-590. https://doi.org/10.1016/j.foodchem.2009.10.028

Gupta, S., & Abu-Ghannam, N. (2011). Recent developments in the application of seaweeds or Seaweed extracts as means for enhancing the safety and quality attributes of foods. *Innovative Food Science & Emerging Technologies, 12*(4), 600-609. https://doi.org/10.1016/j.ifset.2011.07.004

Huisman, J. M. (2010) (Common) Seaweeds of India. Jha, B., Reddy, C. R. K., Thakur, M. C., Rao, M. U. (2009). Seaweeds of India. The Diversity and Distribution of Seaweeds of the Gujarat Coast. Sahoo, Dinabandhu. (2010). Common Seaweeds of India. *Journal of Applied Phycology, 22*(3), 381-383. https://doi.org/10.1007/s10811-010-9524-8

Issac, W. E., & Issac, F. M. (1968). Marine botany of the Kenya Coast: 3 General account of the environment, flora and vegetation. *Journal of East African Natural History, 1968*(116), 7-27.

Jha, B., Reddy, C. R. K., Thakur, M. C., & Rao, M. U. (2009). *Seaweeds of India: The Diversity and Distribution of Seaweeds of Gujarat Coast*. Dordrecht, Netherlands: Springer.

Josephine, M. M., Usha, R., & Rani, S. M. V. (2013). Current status of seaweed diversity and their seasonal availability at Hare Island, Gulf of Mannar. *Science Research Reporter, 3*(2), 146-151.

Kaliaperumal, N. (2017). Studies on phycocolloids from Indian marine algae - A review. *Seaweed Research and Utilisation*, *39*(1), 1-8.

Kaliaperumal, N., & Kalimuthu, S. (1997). Seaweed potential and its exploitation in India. *Seaweed Research and Utilisation*, *19*(1&2), 33-40.

Khan, M. N., Mobin, M., & Abbas, Z. K. (2015). Variation in Photosynthetic Pigments, Antioxidant Enzymes and Osmolyte Accumulation in Seaweeds of Red Sea. *International Journal of Plant Biology & Research, 3*(1), 1028.

Krishnamurthy, R. V., Bhattacharya, S. K., & Kusumgar, S. (1986). Palaeoclimatic changes deduced from $^{13}C/^{12}C$ and C/N ratios of Karewa lake sediments India. *Nature, 323*, 150-152. https://doi.org/10.1038/323150a0

Krishnamurthy, V. (2000). *Algae of India and neighbouring countries I. Chlorophycota*. New Delhi, India: Oxford and IBH publishing.

Krishnamurthy, V. (2005). Seaweeds wonder plants of the sea. *Aquaculture Foundation of India 30*, 72-86.

Krishnan, M., & Dhar, T. P. (2021). Phytoplankton diversity and Physio-chemical features of Achankovil river, India *Ecology, Environment and Conservation, 27*(S), S131-S134.

Lobban, C. S., & N'yeurt, A. D. R. (2006). Provisional keys to the genera of seaweed of Micronesia, with new records for Guam and Yap. *Micronesica, 39*(1), 73-105.

Lobban, C. S., Harrison, P. J., & Duncan, M. J. (1985). *The physiological ecology of seaweeds*. New York, US: Cambridge University Press.

Luning, K. (1984). Temperature tolerance and biogeography of seaweeds: The marine algal flora of Helgoland (Northe Sea) as an example. *Helgoländer Meeresuntersuchungen, 38*, 305-317.

Macler, B. A., & West, J. A. (1987). Life history and physiology of red *algae Gellidium coulleri*, in unialgal culture. *Aquaculture, 61*(3-4), 281-293. https://doi.org/10.1016/0044-8486(87)90156-6

Madhurjaya, B. (2010). *Dried Seaweed Nutritional facts*. Retrieved from https://www.buzzle.com/articles

Malathi, G., Arunprakash, S., Kumar, M. A., Boopathy, A. B., & Rama, P. (2018). Diversity and distribution of macro algae in the Gulf of Mannar. *International Journal of Pharma Research and Health Sciences*, *6*(1), 2264-2268.

Marinho-Soriano, E., Fonseca, P. E., Carneiro, M. A. A., & Moreira, W. S. C. (2006). Seasonal variation in the chemical composition of tropical seaweeds. *Bioresource Technology, 97*(18), 2402-2406. https://doi.org/10.1016/j.biortech.2005.10.014

Mhadhebi, L., Mhadhebi, A., Robert, J., & Bouraoui, A. (2014). Antioxidant, Anti-inflammatory and Antiproliferative effects of aqueous extracts of three Mediterranean brown seaweeds of the genus Cystoseria. *International Journal of Pharmaceutical Research*, *13*(1), 207-220.

Moorjani, S. A., & Simpson, B. (1988). *Seaweeds of the Kenya Coast*. Oxford, UK: Oxford University Press.

Muraoka, D. (2004). Seaweed resources as a source of Carbon fixation. *Bulletin of Fisheries Research Agency Supplement*, *1*, 59-63.

NAAS. (2003). *Seaweed Cultivation and Utilization.* National Academy of Agricultural Sciences*, 5*, 1-22.

Nybakken, J. W. (1992). *Biologi Laut Pendekatan Ekologis*. Jakarta, Indonesia: PT Gramedia Pusaka.

Ortiz, J., Romero, N., Robert, P., Araya, J., Lopez-Hernandez, J., Bozzo, C., Navarrete, E., Osorio, A., & Rios, A. (2006). Dietary fiber, aminoacid, fatty acid and tocopherol contents of the edible seaweeds *Ulva lactuca* and *Durvillaea Antarctica*. *Food Chemistry, 99*(1), 98-104. https://doi.org/10.1016/j.foodchem.2005.07.027

Paul, J. J. P. (2011). Studies on seaweed resources and ecology of southern Coastal region of Tamilnadu. Doctoral Dissertiation. Manonmaniam Sundaranar University.

Pereira, N., & Almeida, M. R. (2014). New records of sea weeds from the Goa Coast, India. *The Journal of the Bombay Natural History Society, 111*(2), 106. https://doi.org/10.17087/jbnhs/2014/v111i2/71736

Phang, S.-M., Wong, C.-L., Pim, P.-E., Yeong, H.-Y., & Chan, C.-X. (2005). Seaweed diversity of the Langkawi Island with emphasis on the northeastern region. *Malaysian Journal of Science, 24*, 77-94.

Pujiastuti, P. (2010). *Pementaatan Scara Lestari Kawasan perairan pantai krakal sebagai sarana pembelajaran.* Universitus Nageri Yogyakarta*.*

Rajauria, G., & Abu-Ghannam, N. (2013). Isolation and partial characterization of Bioactive fucoxanthin from *Himanthalia elongata* Brown seaweed: A TLC-Based Approach. *International Journal of Analytical Chemistry, 2013*, 802573. https://doi.org/10.1155/2013/802573

Rao, M. U., & Chaugule, B. B. (2006). Endangered and extinct seaweeds of Indian shore. In A. Tewari (Eds.), *Recent Advances on Applied Aspects of Indian Marine Algae with Reference to Global Scenario* (pp. 141-146) Central Salt and Marine Chemicals Research Institute: Bhavnagar, India.

Reid, G. K., Chopin, T., Robinson, S. M. C., Azevedo, P., Quinton, M., & Belyea, E. (2013). Weight ratios of the Kelps, *Alaria esculenta* and *Saccharina lastissima*, requires to sequester dissolved inorganic nutrients and supply oxygen for Atlantic salmon, *Salmo salar*, in integrated multi tropic aquaculture systems. *Aquaculture, 408-409*, 34-36. https://doi.org/10.1016/j.aquaculture.2013.05.004

Romdoni, T. A., Ristiani, A., Meinita, M. D. N., Marhaeni, B., & Setijanto. (2018). Seaweed species composition abundance and diversity in Drini and Kondang Merak Beach Java. *Faculty of Fisheries and Marine Science, 47*, 03006.

Sahoo, (2010). The diversity and distribution of seaweeds of the Gujarat Coast. *Journal of Applied Phycology, 22*, 381-383.

Saikia, P., Choudhury, B. I., & Khan, M. L. (2012). Floristic composition and plant utilization pattern in homegardens of Upper Assam, India. *Tropical Ecology, 53*(1), 105-118.

Saloojee, H., & Pettifor, J. M. (2001). Iron deficiency and impaired child development. *BMJ, 323*, 1377. https://doi.org/10.1136/bmj.323.7326.1377

Satheesh, S., & Wesley, S. G. (2012). Diversity and distribution of seaweeds in the Kudankulam Coastal waters, South-Eastern Coast of India. *Biodiversity Journal, 3*(1), 79-84.

Shrinivasan, K. S. (1969). *Phycologia Indica: Icons of Indian Marine Algae* (Vol. 1). Kolkata, India: Botanical Survey of India.

Shrinivasan, K. S. (1973). *Phycologia Indica: Icons of Indian Marine Algae* (Vol. 2). Kolkata, India: Botanical Survey of India.

Silva, P. C., Basson, P. W., & Moe, R. L. (1996). Catalogue of the benthic marine algae of the Indian ocean. (1st ed.). California, US: University of California Press.

Sumich, J. L. (1992). *An Introduction to the Biology of Marine Life.* Lowa, US: Wm. C. Brown Publishers.

Trono, G. C. Jr. (1997). *Field Guide and atlas of the Seaweed resources of the Philippines*. Makati, Philippines: Bookmark.

UNEP, (1998). *Eastern African atlas of Coastal resources Kenya*. United Nations of Environmental Program. Retrieved from https://wedocs.unep.org/handle/20.500.11822/8299;jsessionid=765E3B90A77D1D4206E517150569D94A

van den Hoek, C. (1987). The possible significance of long-range dispersal for the biogeography of seaweeds. *Helgoländer Meeresuntersuchungen, 41*, 261-272. https://doi.org/10.1007/BF02366191

Vivekanandan, E., Srinath, M., Pillai, V. N. R., Immanuel, S., & Kurup, K. N. (2003). Marine fisheries along the southwest Coast of India, p. 757 - 792. In G. Silvestre, L. Garces, I. Stobutzki, C. Luna, M. Ahmad, R. A. Valmonte-Santos, L. Lachica-Alino, P. Munro, V. Christensen, & D. Pauly (Eds.), *Assessment, Management and Future Directions for Coastal Fisheries in Asian Countries* (Vol. 67, pp. 757-792) WorldFish Center Conference Proceedings.

Waghmode, A. V. (2017). Diversity and distribution of seaweeds from the West Coast of Maharashtra. *Journal of Algal Biomass Utilization, 8*(3), 29-39.

WHO. (2008). *Worldwide Prevalence of Anaemia*, World Health Organization, Geneva.

Yadav, S. K., Palanisamy, M., & Murthy, G. V. S. (2018). *New records of two red seaweeds from Kerala Coast, India*. Retrieved from http://nopr.niscair.res.in/handle/123456789/44416

Yarish, C., & Wamukoya, G. (1990). Seaweeds of potential economic importance in Kenya field survey and future prospects. *Hydrobiologia, 204*, 339-346. https://doi.org/10.1007/BF00040254