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A report on diversity and distribution of four non-indigenous red algae (Rhodophyceae) along the Tamil Nadu coast, Southeast coast of India

S. Rameshkumar & R. Rajaram*

Department of Marine Science, Bharathidasan University, Tiruchirapalli-620024, Tamil Nadu, India
*[E. mail: drrajaram69@rediffmail.com]

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The present study was revealed that four Indian invasive seaweeds such as *Acanthophora spicefera, Gracilaria salicornia, Kappaphycus alvarezii* and *Polysiphonia brodiei* were recorded along the Tamil Nadu coast with 55 study sites from Palk Bay and Gulf of Mannar regions, Southeast coast of India. Maximum abundance of *A. spicefera*, *G. salicornia, K. alvarezii* and *P. brodiei* were recorded in Hare Island, Thondi coast, Thonithurai coast and Chinna muttam coast respectively. Highest species dominance (0.3) was recorded for *G. salicornia* during monsoon season and lowest dominance (0.05) was recorded for *A. spicefera* during post monsoon season. Species richness (*D'*) varied from 0.69-0.94 with minimum recorded was *G. salicornia* during monsoon season. Similarly, maximum species richness (*D'*) was recorded for *A. spicefera* during post monsoon season. Species diversity (*H'*) was ranged between 1.70 to 3.19 with the minimum was recorded for *G.salicornia* during monsoon season whereas maximum was recorded for *P. brodiei* during post monsoon season. The dendrogram results showed that three major clusters based on the abundance of species in the study sites. Further, the results revealed that Cluster 1 occupied by more species abundance at more stations and followed by Cluster 2 and Cluster 3.

[Keywords: Non-indigenous seaweeds, Diversity, Distribution, Tamil Nadu coast, India]

Introduction

The large-scale introduction of non-indigenous species is among the greatest threats to the world's biota and subsequent reduction in global biodiversity[1-3]. The non-indigenous or alien or non-native species is otherwise called as biological invasions which have strong ecological impacts on local biota by changing ecosystem functions through community structure and population dynamics[4-10]. These serious impacts may vary depending on the invaded organisms[11-12]. Hence, the biological invasions are great challenge for the conservation of indigenous biodiversity and natural resources. They are considered as one of the most important direct drivers of biodiversity loss and a major pressure on several types of ecosystems with both ecological and economic impacts[13]. In marine systems, invasive species displace the native species, loss of native genotypes, modify habitats, changing community structure, affect food-web properties, impede the provision of ecosystem services, impact human health, and cause substantial economic losses[14-18] and is one of the main threats to biodiversity of marine ecosystems and main issue of growing concern in the marine environments[19-20]. In aquatic ecosystems, aquaculture and related activities (e.g. sport fishing, fishery stock enhancement and ornamental trade) are recognized as important mechanisms of spreading of non-indigenous species[21]. The Global Invasive Species Database (GISD) recommended that 10 marine macro algae such as *Acanthophora spicifera*, *Caulerpa taxifolia*, *Caulerpa webbiana*, *Codium fragile* ssp. *Gracilaria salicornia*, *Hypnea musciformis* , *Kappaphycus* spp., *Polysiphonia brodiei*, *Sargassum fluitans*, and *Undaria pinnatifida* are considered as invasive species around the world. In India, four species of macroalgae like *Acanthophora spicifera*, *Gracilaria salicornia, Kappaphycus alvarezii* and *Polysiphonia brodiei* are known as invasive categories in the marine territories [22-24] which are significantly abundant in India and creates serious impacts in the marine habitats. Therefore, present study was aimed to surveillance and collects these four species around the Tami Nadu coast from Chennai to Kanyakumari coast with total length of 1,076 km for studying their diversity, morphological details, habitat, description and geographical locations. The assessment of ecological impacts of alien marine species has been

recognized as a research priority in recent duration. However, there are still very few precise studies of the impacts of invasive species.

Materials and Methods

This study was carried out at 55 sites in the Tamil Nadu coast with total distance of 1,076 km and totally four invasive seaweeds were collected during the study periods particularly monsoon and post monsoon season (October 2015-March 2016). The study area belongs to different environmental habitats such as open sea, estuary, harbour site, shallow water, sandy beach, rocky coast, muddy flats and Islands. The seaweed samples were mostly abundantly in intertidal rocky shores, sea grass beds, seaweed beds, dead corals, sand and rubbles.

The species *A. spicifera, G. salicornia* and *P. brodiei* were collected from different substratum such as intertidal rocky shores, reef flats, dead corals, shells of gastropods and bivalves. In Islands areas, seaweeds were collected with the help of fishermans during fishing activities. The species *G. salicornia* and *P. brodiei* were also drifted from offshore. *K. alvarezii* were collected in near the cultivation and adjacent sites. The collected seaweeds were identified using the standard taxonomic keys[25-29] and the nomenclatures were updated[30].

Different statistical tools were used to determine the diversity, indices, richness, evenness, by using PAST biodiversity software ver.6.1. Biodiversity indices were calculated following the standard formulae[31-33].

Species diversity (H') $H'=-\sum pi \ln pi$,

Where, pi is the proportion of individuals of each species belonging to the *i*th species of the total number of individuals.

Species richness (D') = $1 - C$; $C = \sum pi2$; $pi = pi/N$

Evenness or equitability (S') = H'/Jns or $H'/\log_2 S$

Results

Results of the present study showed that diversity and distribution of four Indian invasive red seaweeds in and around the Tamilnadu coastal waters. The red seaweeds, *A. spicifera, G. salicornia*, *K. alvarezii* and *P. brodiei* were collected from different localities. The species of *A. spicifera* was frequently dominant at Hare Island followed by Pamban light house, Ariyankundu, Vaalinokkam and Vattakottai sites. The abundance of species for all the stations during the study periods were represented in table 1. *Acanthophora spicefera* was most abundant species during monsoon season at Abbreviation: Most abundant (++++), Abundant (+++), Less abundant (++), Very less abundant (+), Absent (-), Mon - Monsoon, Po. Mon - Post monsoon

Hare Island and Ariyankundu whereas the post monsoon season was favour to most abundance at Pamban light house, Vaalinokkam and Vattakottai sites. Species dominance, Species richness (*D'*) Species diversity (*H'*) and Species evenness (*J'*) were represented for each species (Figs. 1-4). Species dominance was ranged from 0.05-0.06 with minimum and maximum was recorded during post monsoon and monsoon season. Species richness (*D'*) was ranged from 0.93-0.94 with minimum was noted during monsoon season and maximum was noted during post monsoon season. Species diversity (*H'*) was ranged between 3.08-3.19 with lowest was observed during monsoon season and maximum was observed during

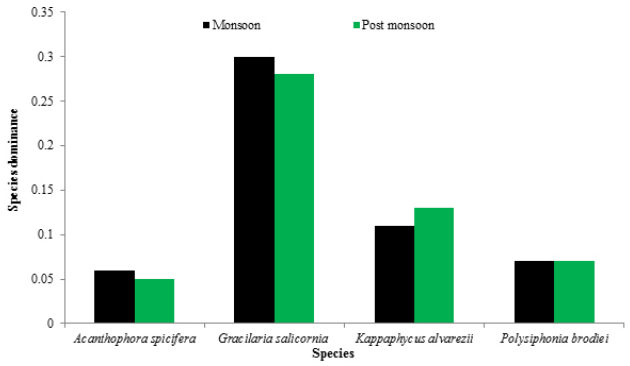

Fig. 1 — Species dominance of four non-indigenous seaweeds at all sites.

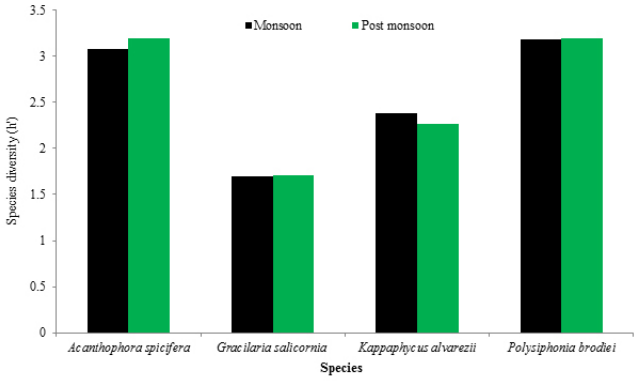

Fig. 2 — Shannon–Weiner diversity indices (*H'*) of four non-indigenous seaweeds at all sites.

Table 1 — Availability of Non-indigenous seaweeds along the Tamil Nadu coast

S. No:	Name of the Stations	Latitude	Longitude	*A. spicefera*		*G. salicornia*		*K. alvarezii*		*P. brodiei*	
				Mon	**Po.Mon**	**Mon**	**Po.Mon**	**Mon**	**Po.Mon**	**Mon**	**Po.Mon**
1	Covelang	12°47.133 N	080°15.170E	-	-	+	+	-	-	+	+
2	Cuddalore	11°42.546 N	079°46.521E	-	-	-	+	-	-	-	+
3	Nagapattinam	10°45. 574N	079°51.035 E	+	+	+	+	-	-	+	-
4	Ammapattinam	10°00.995N	079°14.028 E	+	+	+	+	+	+	+	+
5	Ponnagaram	10°01.642N	079°14.751 E	+	-	+	+	+	+	-	-
6	Kodiakkarai	10°02.435N	079°15.748 E	+	+	+	+	-	-	+	+
7	Kottaipattinam	09°58.376N	079°11.956 E	+	+	++++	++++	+	+	+	+
8	Mimisal	09°55.154N	079°09.118 E	+	+	++	++	++	++	+	+
9	Arasaneripattinam	09°53.441N	079°07.535 E	+	+	+	+	++	++	+	+
10	Thondi	09°44.218N	079°01.140 E	+	+	++++	++++	+	+	+	+
11	Karankadu	09°38.775N	078°57.953 E	-	-	+	+	+	+	+	+
12	Munaikadu	09°23.899N	079°11.349 E	+	+	-	-	+++	++++	+	+
13	Thoonithurai	09°20.974N	079°11.212 E	+	++	+	-	++++	++++	+	+
14	Pamban	09°19.980N	079°12.539 E	+	++	+	-	-	-	+	+
15	Pamban light house	09°19.929N	079°12.511 E	++++	++++	+	+	+	+	+	+
16	Ariyankundu	09°17.717N	079°16.212 E	++++	+++	+	+	+++	++++	+	+
17	Nalupannai	09°17.529N	079°14.408 E	+	-	-	-	+++	++	+	+
18	Villoondithertham	09°17.521N	079°16.212 E	-	-	+	+	-	-	+	+
19	Mangadu	09°17.557N	079°10.549 E	+	+	-	-	++++	++++	++	++
20	Vedhalai	09°17.301N	079°07.579 E	+	+	+	-	+++	+++	+	++
21	Velankanninagar	09°16.780N	079°10.318 E	+	+	+	+	-	-	+	+
22	Nochiyurani	09°16.016N	078°02.043 E	++	++	-	-	-	-	+	+
23	Thalaithoppu	09°16.303N	078°57.152 E	+	+	-	-	-	-	-	-
24	Pudhumadam	09°16.321N	079°00.021 E	+	++	-	-	-	-	+	+
25	Seeniyappadharga	09°15.649N	079°03.981 E	+	+	+	-	+	+	+	+
26	Sallimunthal	09°15.229N	078°52.118 E	++	+	-	-	-	-	-	-
27	Shingle island	09°14.540N	079°13.825 E	+	+	-	-	-	-	+	+
28	Pullivasa island	09°14.295N	079°12.388 E	+	+	-	-	-	-	+	+
29	Kanjarankudi	09°14.255N	078°49.050 E	+	+	+	+	-	-	+	+
30	Kurusadai island	09°14.235N	079°13.256 E	+	+	+	+	-	-	+	+
31	Kilakkarai	09°13.752 N	078°47.661 E	+	+	+	+	-	-	+	+
32	Manoli	09°13.193 N	079°89.091 E	+	+	-	-	-	-	+	+
33	Rameswaram	09°13.171 N	079°19.848 E	+	+	+	+	-	-	+	+
34	Bharathinagar	09°13.067 N	078°45.533 E	+	++	+	-	-	-	+	++
35	Ervadi	09°12.415 N	078°43.536 E	+	+	-	-	-	-	+	+
36	Hare island	09°11.656 N	079°03.414 E	++++	++++	-	-	-	-	+	+
37	Mulli island	09°11.590 N	078°59.918 E	-	-	-	-	-	-	+	+
38	Valai island	09°11.500 N	079°00.172 E	+	+	-	-	-	-	-	-
39	Sadamunivalasai	09°11.434 N	078°43.110 E	++	++	+	+	-	-	+	++
40	Appa island	09°10.326 N	078°50.172 E	+	-	+	+	-	-	-	-
41	Vaalinokkam	09°09.530 N	078°39.383 E	+++	++++	-	-	-	-	+	+
42	Anaipar island	09°09.496 N	078°41.812 E	+	+	-	-	-	-	+	+
43	UppuThanni	09°05.450 N	078°29.280 E	+	+	-	-	-	-	-	-
44	Vembar	09°04.290 N	078°22.383 E	-	-	-	-	-	-	+	+
45	Koswari island	08°51.192 N	078°14.059 E	+	+	+	-	-	-	+	+
46	Vaan island	08°49.686 N	078°13.090 E	+	+	-	-	-	-	-	+
47	Tuticorin Port trust	08°44.896 N	078°11.576 E	+++	++++	-	-	+	+	+	++
48	Punnakayal estuary	08°38.283 N	078°08.518 E	-	-	-	-	+	+	+	+
49	Manapad	08°22.313 N	078°03.953 E	-	-	-	-	+	+	+	+
50	Kuduthalai	08°17.905 N	077°55.684 E	+	+	+	+	-	-	+	+
51	Idinthakarai	08°10.615 N	077°44.648 E	++++	++++	-	-	-	-	+	+
52	Vattakottai	08°07.570 N	077°33.963 E	+++	++++	-	-	-	-	+++	++++
53	Leepuram	08°06.639 N	077°33.438 E	+	+	-	-	-	-	+	+
54	China muttam	08°05.548 N	077°33.845 E	+	++	-	-	-	-	++++	++++
55	Kanyakumari	08°04.682 N	077°32.031 E	+	+	-	-	-	-	-	-

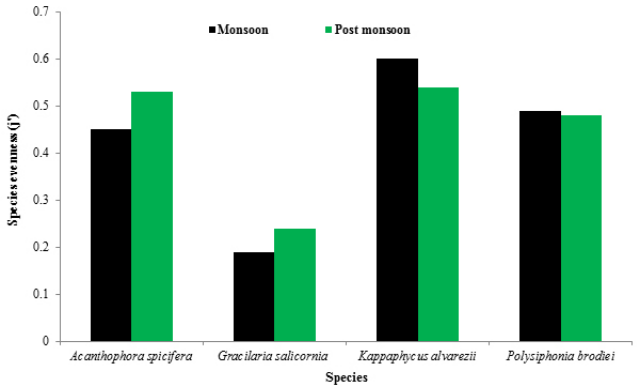

Fig. 3 — Pielou's species evenness (*J'*) of four non-indigenous seaweeds at all sites.

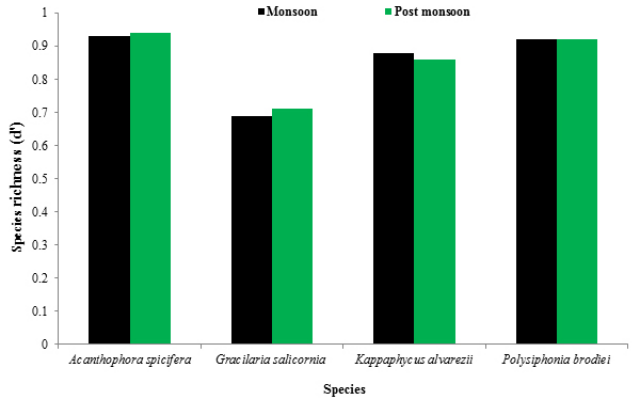

Fig. 4 — Simpson's index of species richness (*D'*) for four non-indigenous seaweeds at all sites.

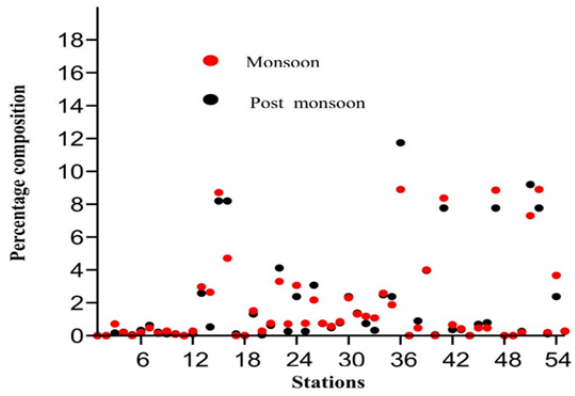

Fig. 5 — Percentage composition of *Acanthophora spicefera* during two seasons at the study sites

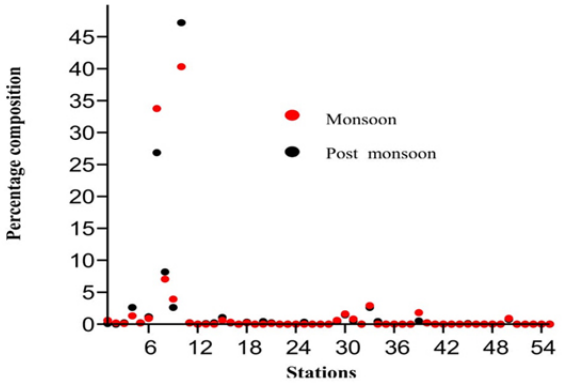

Fig. 6 — Percentage composition of *Gracilaria salicornia* during two seasons at the study sites

post monsoon season. Species evenness (*J'*) was ranged from 0.45-0.53 with minimum was found during monsoon season whereas maximum was found during post monsoon season. The maximum percentage composition of *A. spicefera* was recorded at Hare Island during monsoon season (Fig. 5). *Gracilaria salicornia* mostly recorded in the Palk Bay regions compared to Gulf of Mannar regions. The maximum percentage composition of 47.22% was recorded in Thondi site whereas minimum of 0.1% were recorded at Covelong and also in Thonithurai sites during monsoon season. The minimum percentage compositions of 0.1% were also found at Nagapattinam and Velankanni nagar sites during post monsoon season (Fig. 6).The species of *G. salicornia* was not recorded in some of the study sites during two seasons (Table.1). Species dominance was varied between 0.28-0.30 with minimum and maximum was recorded during post monsoon and monsoon season respectively. Species richness (*D'*) was varied from 0.69-0.71 with minimum was recorded during monsoon season similarly maximum was recorded during post monsoon season. Species diversity (*H'*) ranged between 1.70-1.71 with lowest and highest was recorded during monsoon and post monsoon season respectively. Species evenness *(J')* was ranged from 0.19-0.24 with lowest was recorded during monsoon season similarly highest was recorded during post monsoon season. In the present study, *K. alvarezii* (Solieriaceae) were collected from eighteen sites out of 55 sites. This species was most abundantly in Thonithurai sites followed by Mangadu, Munaikadu etc. The species dominance varied from 0.11-0.13 with minimum and maximum was recorded during monsoon and post monsoon season respectively. Species richness (*D'*) varied from 0.86-0.88 with minimum and maximum was recorded during post monsoon and monsoon season respectively.

Species diversity (*H'*) was ranged from 2.27-2.38 with minimum was observed during post monsoon whereas maximum was observed during monsoon season. Similarly, species evenness (*J'*) was ranged from 0.54-0.6, the minimum was noted during post monsoon and maximum was noted during monsoon season. The maximum percentage composition of 25.99% was recorded in Thonithurai site during post monsoon season and minimum of 0.13% was recorded in Ammapattinam site during this same season (Fig. 7). *P. brodiei* (Rhodomelaceae) was recorded at Chinnamuttam and Vattakottai sites with maximum abundance were recorded during post monsoon season compared to monsoon season. The maximum percentage composition of 18.69% was recorded at Chinnamuttam during post monsoon season and minimum of 0.1% was recorded at Nagapattinam during monsoon season (Fig. 8). The lowest and highest species dominance 0.07 was recorded during the two seasons similarly; the species richness (*D'*) 0.92 was recorded during the two seasons. Species diversity (*H'*) was ranged between 3.18 - 3.19 with lowest and highest were recorded during monsoon and post monsoon season respectively. Species evenness (*J'*) was ranged from 0.48 - 0.49 with minimum was recorded during monsoon season and maximum was recorded during post monsoon season. Comparative alpha diversity profiles for all the stations during monsoon and post monsoon were presented (Fig. 9-12). The alpha diversity increased significantly (P<0.001) with increasing contribution of stations. In *A. spicefera*, the sensitivity of alpha diversity across the study areas significantly decreased (P>0.001) with totally 8 stations i.e. Covelang, Cuddalore, Karankadu, Villoondithertham, Mulli Island, Vembar, Punnakayal

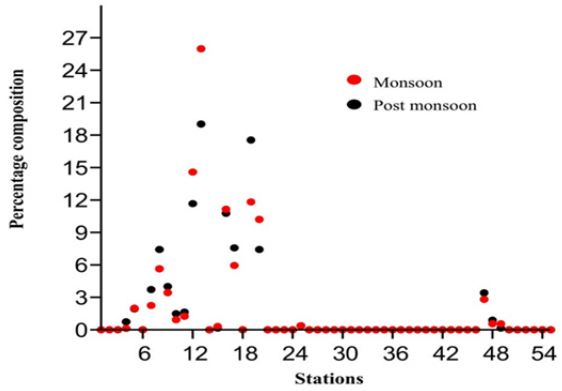

Fig. 7 — Percentage composition of *Kappaphycus alvarezii* during two seasons at the study sites

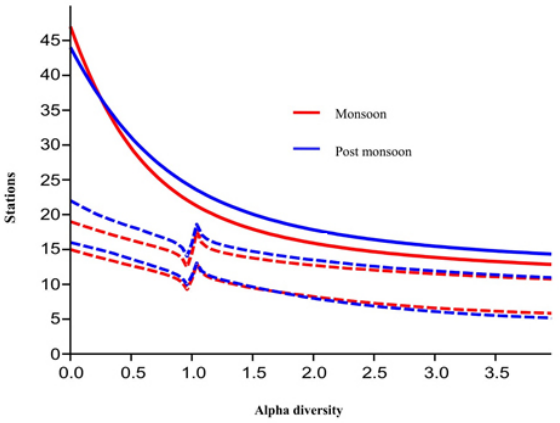

Fig. 9 — Diversity profiles of *Acanthophora spicefera* during two seasons at the study sites

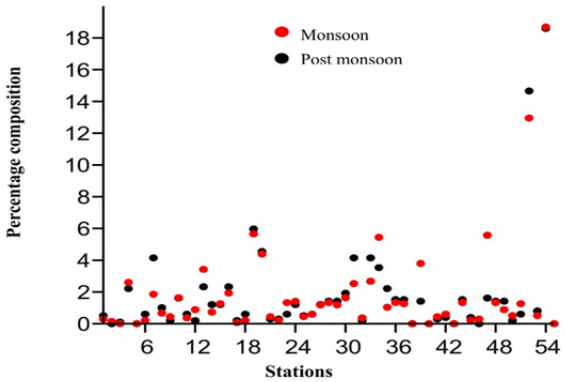

Fig. 8 — Percentage composition of *Polysiphonia brodiei* during two seasons at the study sites

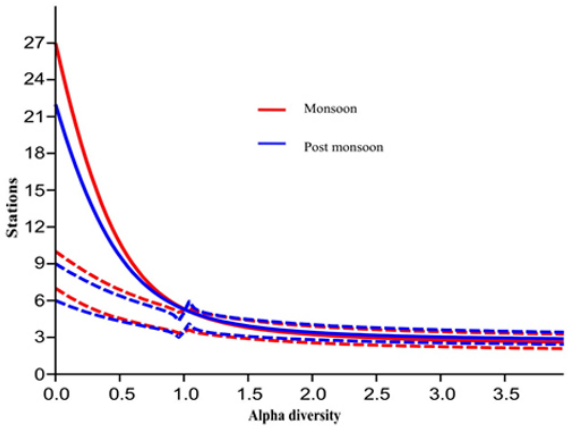

Fig. 10 — Diversity profiles of *Gracilaria salicornia* during two seasons at the study sites

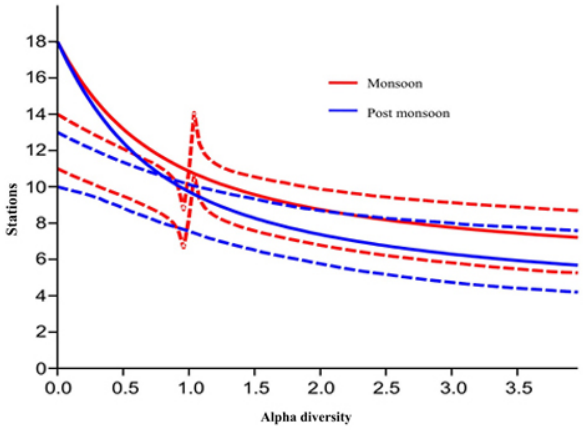

Fig. 11 — Diversity profiles of *Kappaphycus alvarezii* during two seasons at the study sites

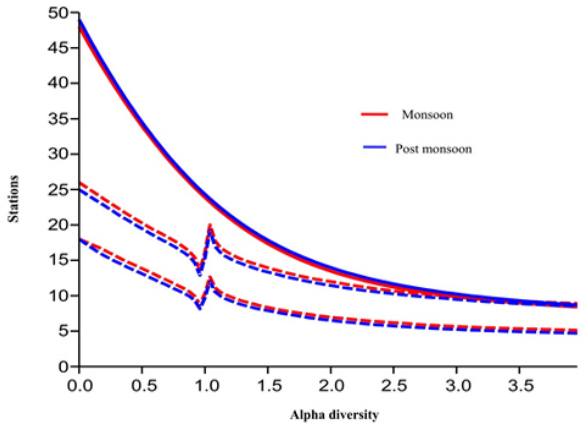

Fig. 12 — Diversity profiles of *Polysiphonia brodiei* during two seasons at the study sites

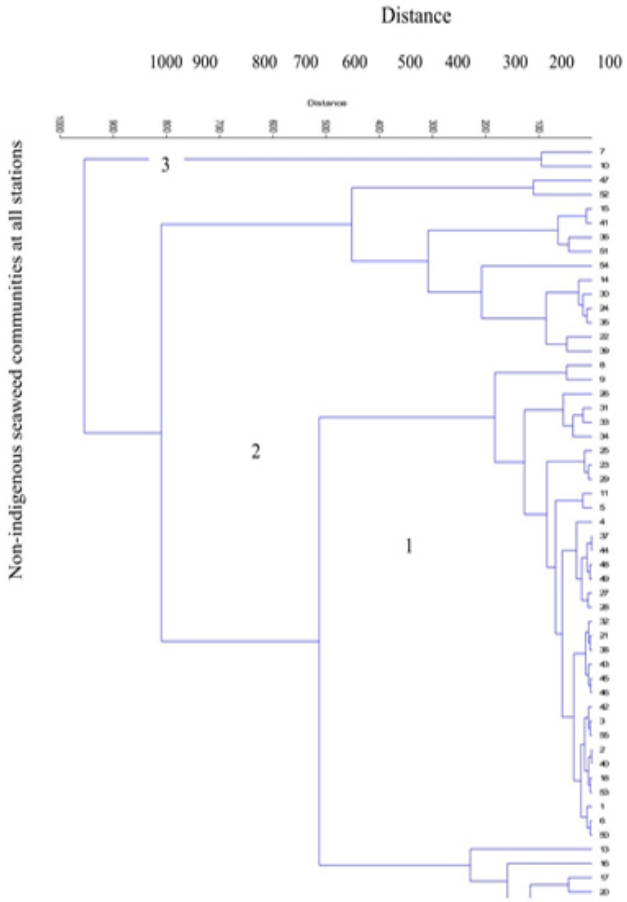

Fig. 13 — Dendrogram for hierarchical cluster analysis species distributions from fifty-five stations.

estuary and Manapad. The contribution of alpha diversity increased significantly (P<0.05) with Pamban light house, Hare island and Idinthakarai stations. *K. alvarezii* was increased (P<0.05) at Thoonithurai and Mangadu stations with significantly decreased (P> 0.001) in 37 stations. In *G. salicornia* significantly increased (P<0.05) at Kottaipattinam and Thondi stations with significantly decreased (P> 0.001) in 27 stations.

The species *P. brodiei* was significantly increased (P<0.05) only at China muttam station whereas significantly decreased (P> 0.001) at totally 8 stations during monsoon and post monsoon seasons. Cluster analysis performed the sampling sites into three major clusters namely Cluster 1, Cluster 2 and Cluster 3 for 55 sites. The three major clusters classified based on the abundance of species in the study sites. (Fig. 13). The results showed that Cluster 1 occupied by more species abundance at more stations and followed by Cluster 2 and Cluster 3.

Discussion

Study of diversity and distribution of seaweeds in Indian waters were carried out by several authors which is a unique marine habitat characterized by a high biodiversity[34-43]. The observed seasonal distribution of seaweeds may be related to the life history of the alga, particularly the dispersal abilities of spores and the variation of distributions were also differed between sites and seasons. The nature of the substratum, hydrological parameters, nutrient availabilities and biotic factors such as competition of parasites, epiphytes, symbionts, grazers, diseases, space and light also determines the algal distribution[44]. In our present study, the rocky substratum has more species abundance during the

monsoon followed by post monsoon season. Sahayaraj *et al*.[45] reported that rocky substratum has good natural substratum for diversity and distribution of seaweeds. This present findings were supported by Sathees and Wesley[46] and Canciyal *et al.*[47]. Similarly, Krishnamurthy[48] reported that the seaweeds drifted from offshore to seashore during rainy and after heavy rain. *Acanthophora spicifera* (Rhodomelaceae) is a marine red algae which is native range to Florida and the Caribbean sea and alien range to Marshall Islands and United States (USA) further in most of the countries the bio status not specified including in India. In our study, this species was reported at 47 study sites out of 55 sites which were dominated at Hare island, Tuticorin Port trust, and Nochiyurani, which was also reported in Hare Island Mary Josephine *et al.*[49] and Kalimuthu *et al.*[50] reported at Mandapam coast; Saravanan *et al*.[51] recorded from at Nochiyurani coast of Gulf of Mannar. Canciyal *et al*.[52] reported from Tuticorin coastal waters along the south east coast of India and Kanyakumari coast by Sahayaraj *et al*.[45] This present findings was new distribution records for this species dominance at Pamban light house, Ariyankundu, Vaalinokkam, Idinthakarai, Vattakottai, Sadamunivalasai, China muttam, Bharathinagar, Sallimunthal, Pudhumadam, Thoonithurai and Pamban sites.

Gracilaria salicornia (Gracilariaceae) is one of the most successful invasive algae on reef flat area and native to Philippines and alien range to United States (USA). The bio status of *G. salicornia* is not specified in many countries including India, currently, very limited research has been conducted on *G. salicornia* in both its native and non-indigenous ranges. Our present findings conducted that diversity and distribution of this species which was dominated at Kottaipattinam, Thondi followed by Mimisal which was reported by Canciyal *et al.*[53] and Mary Josephine *et al.*[49] from Hare island, Gulf of Mannar. Canciyal *et al*.[52] reported from Tuticorin coastal waters. The mode of way of dispersal is not recorded in India however the present study conducted for diversity and distribution patterns was new information for this species. *Kappaphycus alvarezii* are largest tropical red seaweeds which have been introduced in various parts of the world for kappa carrageenan. This species can easily grow from vegetative fragments with fast growing species. *Kappaphycus alvarezii* is a tough, fleshy, firm; algae that can grow up to 2m tall which is native to Philippines[54] and was alien range to various countries. In the present study, diversity and distribution of *K. alvarezii* recorded in various parts of Palk Bay waters in Ramanathapuram district (Mandapam, Munaikadu, Vedhalai, Pamban etc.), Pudhukkottai district (Kottaipattinam) and Tuticorin district (Mullaikadu) which species cultivation was also reported by Periyasamy *et al.*[55].

Many ecological impacts study was carried out for same species in around the world. Conklin and Smith[56] reported that *Kappaphycus* sp a serious danger to the coral reefs. Woo *et al.*[57] states that, observations have shown that the alga is able to coalesce into the tissue of the coral, providing a strong means for attachment, and thus allowing the alga to persist in high wave energy environments. Woo[58] documented fragments of *Kappaphycus* spp suggest that fragments created by physical disturbance can be carried by waves and currents to new locations where they can possibly establish. Chandrasekar *et al.*[59] conclude from the results of their study, *K. alvarezii* which has established on the branching corals are destroying them through shadowing and smothering impact of the infestations. Rameshkumar and Rajaram[60] reported that macro faunal communities were decreased by cultivation of *K. alvarezii*. In the present study, the diversity and distribution of this species was new recorded.

Polysiphonia brodiei (Rhodomelaceae) is a red macro algae with native range to North Europe and North Africa[61] whereas alien range to Australia, Canada, New Zealand, United States (USA). Bio status not specified in India, Japan, Kuwait, Qatar and Saudi Arabia. The species abundance was recorded at Vattakottai and Chinnamuttam followed by Mangadu sites which was reported by Sahayaraj *et al*.[45] from southern districts of Tamil Nadu. However, the diversity and distribution of this species has very limited so, our present findings more significant to biodiversity study. At present time, the impact of bio invasive study was not conducted in Indian marine environment however, this present study was strongly involved the diversity and distribution of this species which is basic step to further ecological study.

Conclusion

These four invasive seaweeds were recorded at more stations along the Tamil Nadu coast. Global Invasive Data Base also recommending that these four rhodophyceae members were invasive for Indian marine waters. The invasive has created more impacts

on marine ecosystem such as algal bloom, modified natural benthic community, ecological dominants, grows over at coral reefs, fouling on moving vessels were reported by different researchers. However, only very limited EIA studies were conducted for *Kappaphycus* spp and other species such as *A. spicifera, G. salicornia* and *P. brodiei* is not studied for ecological impacts.

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