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MULTIVARIATE ANALYSIS OF MARINE ALGAL ASSEMBLAGES AND THEIR DISTRIBUTION PATTERN ALONG THE SINDH COASTAL AREA OF PAKISTAN

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Abstract

Algae play an important role in marine and fresh water environment. They are used in a variety of ways, including as therapeutic agents and constitute one of the important natural resource. Many environmental factors such as pollution are disrupting their richness, composition and abundance of coast seaweeds. This investigation focuses on the quantitative community description of composition and structure of seaweed assemblages using multivariate approaches for the Sindh cost, Pakistan, Principal Component Analysis (PCA) and Ward's agglomerative clustering techniques were employed to analyze the data structure. A total of 77 seaweed species were recorded of which 20% belonged to Chlorophyta, 45% to Phaeophyta and 34% were from the phylum Rhodophyta. *Jania capillacea, Codium reductum, Udotea indica,Caulerpa scalpelliformis, Melanothamnus somaliensis, Chaetomorpha antennia, Codium iyengarii, Caulerpa racemosa, Caulerpa veravalensis* and *Ulva rigida* are usually abundant species in summer, while in winter season *Colpomenia sinuosa, Iyengaria nizamudinii, Iyengaria stellata, Lobophora variegate, Cystoseira indica, Dictyota dichotoma, Padina gymnospora, Padina pavonica ,Sargassum filifolium, Sargassum crassifolium, Dictyota divaricate, Dictyota indica, Codium iyengarii, Coelarthrum muelleri, Champia globulifera* and *Gelidium folifera* attain greater abundance. A group of species are usually associated with particular habitats forming assemblages (communities). The assemblages characteristic of rocky / /sandy pools. Comprise of *Caulerpa* spp., *Codium* spp., *Iyengaria* spp., *Cystoseira* spp. *and Dictyota* spp., the species with sandy/rocky *beaches* include *Sargassum* spp., *Padina* spp., *Colpomenia sinuosa, Laurencia pinnatifida* and *Melanothamnus somaliensis.* Muddy habitats are commonly occupied by communities having *Entomorpha flexsousa, Chaetomorpha antennia* and *Polysiphonia adriatica* .as the dominant species. Algal biomass was highest in February and lowest in July. Principal component analysis (PCA) ordination configuration and the bi-plot disclosed the distribution pattern of species and their assemblages (associations) and the relationships with habitats types. Cluster analysis effectively exposed the underlying group structure (i.e., communities or assemblages) and complemented the results of PCA.

Key words: Sea weeds, quantitative, multivariate, cluster analysis, PCA.

Introduction

Seaweeds serve as a vital component in maintaining the aquatic food chain, and their absence or low abundance in a water body indicates an aquatic imbalance. Several chemicals are isolated from them and used as stabilisers and stiffeners in the food, cosmetics, and biotechnology industries (Hu *et al.*, 2021; Singh *et al.*, 2018; Carneiro-da-Cunha *et al*., 2011). Human activity such as urbanisation, and industrialisation, on the other hand, have disrupted the distribution, abundance and diversity of seaweeds.

Some metal pollutants, such as nickel and zinc, are naturally present, and their discharges into the environment might be natural or human-caused (Kumar & Kumar, 2019). Many subsurface metal pollutants are released into the surface environment as a result of this intense and continuous anthropogenic disturbance, has considerably degraded water quality.

The Sindh Coast which stretches 350 km is one of the most fertile coasts in the world, but it is threatened by anthropogenic disturbance and pollution. Seaweeds are important economically, thus this natural riches should not be lost in a developing country like Pakistan. Many factors influence the distribution and abundance of algal flora of coastal areas; this important life-form of plants plays an important part in the marine environment, and further research would help us better understand the marine ecosystem's food chain. In view of the above, the current study was conducted in order to improve the conservation of seaweeds along the Sindh Coast. Many researchers, including (Boergeson, 1915; Anand, 1940, 1943; Nizamuddin & Saifullah, 1967, 1978; Ahmed *et al*., 1989; Sheikh & Shameel, 1995; Afaq-Huusain & Shameel, 1997; Nizamuddin & Gul, 2007; Ahmed *et al*., 1989) have investigated the anatomy, morphology and taxonomy of seaweeds, though algal community studies have been scanty. Saifullah (1973) conducted quantitative study of Seaweed communities at Buleji, Karachi and Saifullah *et al*., (1984) examined the dominance diversity relations of algal communities at Karachi coast.

The major goal of the current study is to obtain useful and comprehensive ecological information on the diversity and distribution of seaweed assemblages along Pakistan's Sindh coast. In Pakistan, however, there is a scarcity of information about the identity and diversity of economically important seaweed species. The data and the results obtained here can serve as a starting point for future in depth ecological studies in this area, as well as for managing and discovering the seaweed associations and their controlling factors.

The focus of our study is to provide quantitative comprehensive description regarding the diversity, abundance and distribution of assemblages, seaweeds along the Sindh coast of Pakistan. Multivariate techniques

are employed to examine the species distributions, assemblage, multilateral relations between habitats and algal assemblages and underlying group structure inherent in the data set. Such studies have not been conducted in the past by the previous investigators, therefore, no detailed information on these aspects is available for the seaweed communities of Pakistan coast.

Material and Methods

The sampling was performed from the sites that were less polluted and least disturbed. During the sampling period (February 2016 - January 2017). Sampling sites and the coastal area is shown in Fig. 1. The sites and their description are given in Table 1. At each sampling site 25 quadrats (each of 25 X 25 cm size) were made every month throughout the sampling period. The quadrats were placed at every 20 meter interval The macrophyte distribution pattern along with the zonations in the coastal area was also keenly observed. The collection was made during low tide. The algae were collected using hand and knife. The site coordinates were recorded using GPS. In each month the occurrence or absence of all the collected species was recorded. At several locations, transect lines were set in 1m increments. They served as a reference for lining up the quadrats along the transect in a straight line.

Fig. 1. Map shows the area of Sindh coast from where sampling was performed at different sites.

Table 1. The sampling sites with Geo morphological/ Topographical features of Sindh coast.

Site No.	Sampling sites	Geo morphology/Topography
1.	Chach Jaan Khan (Sujawal)	Creek Area (Mangrove, muddy beach)
2.	Shah Bandar (Sujawal)	Creek Area (Mangrove, muddy beach)
3.	K.T. Bandar (Thatta)	Creek Area (Mangrove, muddy beach)
4.	Manora (Karachi)	Rocky area with pools and sandy beaches
5.	Sandspit (Karachi)	Sandy area with pools
6.	Hawksbay (Karachi)	Sandy coast
7.	Buleji (Karachi)	Rocky platforms with pools (Rocky & sandy)
8.	Paradise Point (Karachi)	Rocky area with pools and sandy beaches
9.	Sonehra Point (Karachi)	Rocky areas with sandy beaches
10.	Mubarak Village (Karachi)	Sandy beaches and rocky platforms

Collection of data and samples: In order to collect quantitative data, sites that were least polluted and undisturbed were chosen. Three transects perpendicular to the beach were used to visually observe the zonation profile and algal-macrophyte distribution pattern. The detailed visual observations on the algal flora of all sites were continued up to 2018 though no quantitative data were gathered beyond Jan. 2017. During low tide, different species of macrophyte specimens were painstakingly collected by hand and with a knife, for specimen collection as well as biomass estimation. The macro-algal samples (filamentous and thalloid algae) were collected in plastic bags containing 4% formalin solution (for herbaria collection). These were then brought to laboratory and preserved in glass jars. The filamentous algal specimens were observed under trinocular microscope. whereas the macroalgae were observed through unaided eye and photographed with the help of digital camera (Canon IXUS 185), The taxonomic identification of all the collected taxa up to species level were carried out with the help of available literature (Anand, 1940, 1943; Abbas, 2010; Abbas & Shameel, 2009, 2011) and the Algal Herbaria at Biological Research Centre, University of Karachi (Prof. Dr. M. Shameel and Prof. Dr. M. Nizamuddin collection) and Department of Botany, Federal Urdu University, Karachi. Voucher specimens are deposited at Federal Urdu University Herbarium. The relative frequency, density, cover were combined to obtain importance value index (I.V.I) (Curtis & McIntosh, 1951). These attributes were calculated using the methods proposed by Mueller–Dombois & Ellenberg, (1974) and Ahmed & Shaukat, (2012). The species having highest importance value was regarded as the most dominant species in the stand or site (Brown & Curtis, 1952). The algal communities were identified using the first three or four dominant species (having high IVI) as suggested by Curtis & McIntosh, (1950, 1951). The Phytosociological attributes were computed using a program Phyto-Tables developed by one of us (S.S.S.).

Additionally, biomass of algae (fresh weight and dry weights) were determined by sampling using quadrat method, as described above for each month.

Results and Discussion

The seaweed distribution and prevalence at Sindh coast has added significantly to the knowledge regarding seaside environments corresponding to the geo-morphological provisions including the presence of mud flats, rough stony beeches to rocky surfaces with lagoons or pools of various sizes and the associated algal flora. One more significant element of this coast is the event of month to month variation in the average drift levels and accretion of silt at waterway mouths in certain areas particularly at Buleji (Karachi), Manora (Karachi) and Paradise point (Karachi) stations. These shoreline qualities at Sindh impact sudden changes in dispersion of macroalgae.

The sampling sites, their geomorphological/ topographical features are given in Table 1. From the Sampling sites (Fig. 1) it is elucidated that significant occurrence of macro algae was seen in Manora and Buleji where 20 common species i.e., *Colpomenia sinuosa*, *Dictyota dichotoma*, *D. indica*, *D. hauckiana*, *Lobophora variegata*, *S. filifolium*, *S. boveanum*, *S.tenerrimum*, *S. vulgare*, *Iyengaria nizamudinii*, *I. stellata*, *Cystoseira indica*, *P.adina pavonica*, *P. gymnospra*, *Spatoglossum variabile*, *S.typopodium zonale*, *Stokyia indica*, *Halymenia porphyroides* and *Jania adherence* were recorded as abundant or dominant (Fig. 8). However, 14 species were common in Sandspit, Hawksbay and Paradise point areas including *Caulerpa taxifolia*, *Udotea indica*, *Cystoseira indica*, *Colpomenia sinuosa*, *Dictyota indica*, *Iyengaria* sp., *Sargassum* spp., *Padina* spp., *Gelidium pusillum*, *Jania adherense*, *Laurencia pinnatifida* while *Codium iyengarii* and *Dictyota indica* were most common in Sonehra point and Mubarak Village, though, *Enteromorpha flexsousa* was dominant in Chach Jaan Khan, Shahbandar and at K.T. Bandar. It is noteworthy that no such studies exist that cover the entire Sindh coast although, phycologists have focused a lot on anatomical, morphological, and taxonomic work along specific areas of Karachi and Sindh coast. However, Saifullah, (1973) reported 48 species from Buleji, Karachi, Hameed & Ahmed (1999 a,b) enumerated 85 species., from Buleji and described various microhabitats associated with the algae. Abbas, (2010) reported 36 species of Pheophyta from Karachi coast, Nazim *et al*., (2012) recorded 58 types of marine algae from Buleji, Karachi Sindh coast and Qari, (2017) put forth 60 species, from Nathiagali ocean side, Karachi. On the other hand, the current study has recorded a total of 64 species from the entire Sindh coast which though somewhat close to other studies but slightly lower than the estimates of other authors considering that the record of 64 species is based on all sites. This declining pattern of algal species richness of the Sindh coastline could be a result of certain degree of pollution and other forms of disturbances.

Quantitative description of algal vegetation: The importance value index (IVI) of seaweeds calculated for each of the sampling sites indicated their relative abundance. A total of 39 species occurred during the summer season (all sites included, Tables 1, 2 and Fig. 8). The species that occurred with highest IVI were *Caulerpa racemosa*, *Chaetomorpha antennia*, *Coelarthrum muelleri*, Remarkably, *Chaetomorpha antennia* occurred with very high IVI (195 to 300) in sites 1, 2 and 3 respectively. Whereas, species like *Solieria robusta*, *Gelidium folifera Padina pavonica* generally were represented with low importance value (Fig. 8).

In winter season (Table 3) *Polysiphonia adriatica* showed the highest importance value index, followed by *Polysiphonia nizamuddinii*, *Sargassum tenerrimum* and *Dictyota indica*. While *Padina gymnospora*, *Caulerpa taxifolia*, *Spatoglossum qaiserabasii* and *Galaxaura oblongata* usually occurred with low importance value.

Table 2. Importance value index (IVI) of the seaweeds from the ten sites of coastal area of Sindh for summer season.

S. No.	Species name	1	2	3	4	5	6	7	8	9	10
						Chlorophyta					
1.	*Caulerpa taxifolia*	0	0	0	12	6	0	12	9	6	0
2.	*Caulerpa racemosa*	0	0	0	0	30	0	6	6	36	54
3.	*Caulerpa scalpelliformis*	0	0	0	6	0	15	18	12	0	0
4.	*Caulerpa chemnitzia*	0	0	0	18	9	0	15	9	0	0
5.	*Caulerpa veravalensis*	0	0	0	33	6	0	9	18	18	0
6.	*Chaetomorpha antennia*	210	300	195	0	0	0	0	12	0	0
7.	*Codium iyengarii*	0	0	0	0	45	0	12	3	75	60
8.	*Codium boergesenii*	0	0	0	0	0	0	18	0	12	0
9.	*Codium indicum*	0	0	0	9	0	9	15	12	15	0
10.	*Codium reductum*	0	0	0	15	0	12	9	6	6	0
11.	*Halimeda tuna*	0	0	0	12	9	24	9	0	0	0
12.	*Udotea indica*	0	0	0	18	9	12	15	0	0	0
13.	*Ulva rigida*	0	0	0	12	0	0	12	9	18	12
14.	*Ulva fasciata*	0	0	0	27	15	15	12	15	12	54
15.	*Valoniopsis pachynema*	0	0	0	6	3	0	0	0	0	0
						Phaeophyta					
16.	*Colpomenia sinuosa*	0	0	0	0	0	6	6	0	0	0
17.	*Dictyota indica*	0	0	0	0	15	9	3	0	0	0
18.	*Iyengaria nizamudinii*	0	0	0	0	0	12	0	15	0	0
19.	*Iyengaria stellata*	0	0	0	0	6	27	9	6	0	0
20.	*Padina pavonica*	0	0	0	0	3	0	0	6	0	0
21.	*Padina tetrastromatica*	0	0	0	6	9	27	9	0	0	0
22.	*Sargassum filifolium*	0	0	0	0	27	6	9	0	0	0
23.	*Sargassum tenerrimum*	0	0	0	0	21	0	0	0	12	24
24.	*Spatoglossum variabile*	0	0	0	6	0	0	9	0	0	0
25.	*Stoechospermum marginatum*	0	0	0	0	15	15	6	9	0	0
26.	*Polysiphonia nizamuddinii*	27	0	0	6	0	0	0	12	0	0
27.	*Polysiphonia adriatica*	63	0	105	0	0	0	0	0	0	33
						Rhodophyta					
28.	*Ceramium manorense*	0	0	0	12	6	0	0	6	0	0
29.	*Champia globulifera*	0	0	0	9	9	0	0	9	0	0
30.	*Coelarthrum muelleri*	0	0	0	6	6	21	6	18	0	0
31.	*Gelidium folifera*	0	0	0	18	0	9	0	9	0	0
32.	*Gelidium pusillum*	0	0	0	0	0	18	15	15	15	27
33.	*Geladium usmanghanii*	0	0	0	0	15	0	12	9	0	0
34.	*Hypnea musciformis*	0	0	0	0	9	15	0	15	36	12
35.	*Jania adherense*	0	0	0	0	9	0	12	9	12	0
36.	*Jania capillacea*	0	0	0	15	6	18	15	6	0	0
37.	*Laurencia obtusa*	0	0	0	21	0	18	0	9	0	0
38.	*Laurencia pinnatifida*	0	0	0	24	0	6	12	6	12	12
39.	*Melanothamnus somaliensis*	0	0	0	0	12	0	15	12	15	12
40.	*Solieria robusta*	0	0	0	9	0	6	0	18	0	0

Table 3. Importance value index of seaweeds from the ten sites of coastal areas of Sindh for winter season.

S. No.	Species name	1	2	3	4	5	6	7	8	9	10
						Chlorophyta					
1.	*Caulerpa faridii*	0	0	0	9	0	0	9	0	0	0
2.	*Caulerpa Scaliformis*	0	0	0	6	6	0	0	0	0	9
3.	*Caulerpa taxifolia*	0	0	0	3	0	0	0	0	3	0
4.	*Caulerpa racemosa*	0	0	0	0	0	0	3	0	12	16.59
5.	*Caulerpa chemnitzia*	0	0	0	0	0	0	4.2	0	0	0
6.	*Caulerpa veravalensis*	0	0	0	0	0	0	4.86	0	0	0
7.	*Codium iyengarii*	0	0	0	3	0	0	3	9.51	27	33
8.	*Codium latum*	0	0	0	6	0	0	0	9	0	0
9.	*Entomorpha flexsousa*	120	300	189	0	0	0	0	0	0	0
10.	*Halimeda tuna*	0	0	0	6	0	0	3	6	0	0
11.	*Valoniopsis pachynema*	0	0	0	9	0	3	1.2	4.5	0	6
12.	*Udotea indica*	0	0	0	3	0	0	6	6.69	6	21
13.	*Ulva fasciata*	0	0	0	7.95	0	0	3	0	0	0
						Phaeophyta					
14.	*Colpomenia sinuosa*	0	0	0	6.06	0	0	9	12.84	0	0
15.	*Cystoseira indica*	0	0	0	7.35	0	6.75	9	9	3	0
16.	*Dictyota dichotoma*	0	0	0	9.63	0	1.44	9	3	0	0
17.	*Dictyota divaricata*	0	0	0	6	6	9	3	0	0	0
18.	*Dictyota flabellata*	0	0	0	0	18	3	3	0	0	0
19.	*Dictyota hauckiana*	0	0	0	6	0	0	3	0	0	0
20.	*Dictyota indica*	0	0	0	11.01	12.63	21.42	6	0	18	24
21.	*Dictyopteris divaricata*	0	0	0	3	0	6	4.5	0	0	0
22.	*Dictyopteris polypodiodes*	0	0	0	0	3	0	5.4	0	0	0
23.	*Dilophus alternans*	0	0	0	0	3	0	3	0	0	0
24.	*Iyengaria nizamudinii*	0	0	0	6	9	15	5.79	24	0	0
25.	*Iyengaria stellata*	0	0	0	20.07	15	18	17.01	7.11	6	0
26.	*Jolyna laminarioides*	0	0	0	0	0	0	18	0	0	0
27.	*Lobophora variegata*	0	0	0	10.71	0	9	12	12.6	0	0
28.	*Padina afaqhussainii*	0	0	0	0	27	9	0	0	0	0
29.	*Padina antillarum*	0	0	0	0	0	0	3	0	0	0
30.	*Padina gymnospora*	0	0	0	14.85	9	5.7	3	0	0	24
31.	*Padina pavonica*	0	0	0	1.89	0	6	9	0	0	0
32.	*Padina nizamudinii*	0	0	0	0	0	3	3	0	0	0
33.	*Padina tetrastromatica*	0	0	0	0	0	18	6	0	0	0
34.	*Polysiphonia nizamuddinii*	66	0	27	6	0	0	0	12	0	0
35.	*Polysiphonia adriatica*	114	0	84	0	0	0	0	0	0	33
36.	*Sargassum boveanum*	0	0	0	12	36	6.12	9	0	18	0
37.	*Sargassum crassifolium*	0	0	0	9	18	24	6	0	0	0
38.	*Sargassum filifolium*	0	0	0	6	17.19	21	3	0	15	12
39.	*Sargassum tenerrimum*	0	0	0	0	24	39	6	6	0	0
40.	*Sargassum vulgare*	0	0	0	3	15	10.95	3	0	21	42.72
41.	*Spatoglossum qaiserabasii*	0	0	0	6	0	0	3	0	0	0
42.	*Spatoglossum shameelii*	0	0	0	3	0	12	3	0	0	0
43.	*Spatoglossum variabile*	0	0	0	9	18	0	6	0	0	0
44.	*Stoechospermum marginatum*	0	0	0	6	0	14.01	0	9.75	0	0
45.	*Stokyia indica*	0	0	0	9	6	0	0	0	8.46	0
46.	*Stypopodium zonale*	0	0	0	10.8	6	8.7	6	0	0	0
						Rhodophyta					
47.	*Acanthophora spicifera*	0	0	0	0	0	0	6	9	0	0
48.	*Ahnfeltia plicata*	0	0	0	3.75	0	0	3	12	0	0
49.	*Botryocladia leptopoda*	0	0	0	4.68	0	0	1.8	7.5	0	0
50.	*Ceramium manorense*	0	0	0	0	0	0	6	3	0	0
51.	*Champia globulifera*	0	0	0	0	0	0	3	6	21	15
52.	*Champia plumose*	0	0	0	0	0	0	1.2	3	27	9
53.	*Coelarthrum muelleri*	0	0	0	9	0	0	6	12	42	21
54.	*Galaxaura oblongata*	0	0	0	0	0	0	6	3	0	0
55.	*Gelidium folifera*	0	0	0	6	3	0	0	7.05	0	8.25
56.	*Gracilaria verrucosa*	0	0	0	0	0	0	6	19.77	0	0
57.	*Halymenia porphyroides*	0	0	0	3	15	8.7	10.02	9	21	0
58.	*Hypnea musciformis*	0	0	0	0	9	15.21	3	12	51.54	0
59.	*Jania adherense*	0	0	0	7.77	0	0	3	1.5	0	0
60.	*Jania capillacea*	0	0	0	0	0	0	3	9.6	0	0
61.	*Laurencia obtusa*	0	0	0	11.28	12.18	0	6.9	7.5	0	0
62.	*Sarcodia dichotoma*	0	0	0	5.4	0	6	3	13.5	0	25.44
63.	*Sarconema furcellatum*	0	0	0	7.8	6	0	6	6	0	0
64.	*Scinaia filiformis*	0	0	0	1.8	0	0	5.7	6.48	0	0
65.	*Scinaia indica*	0	0	0	3	6	0	3	11.1	0	0
66.	*Solieria robusta*	0	0	0	1.2	0	0	3.42	9	0	0

Table 4. Principal component analysis (PCA) of summer season (April to October) of algal assemblages at Sindh coast, Pakistan.

Comp.	Eigen value	% Variance	Cumulative variance	First four Eigenvector coefficients	Associated species
I	12.497	31.2	31.2	0.259	*Jania capillacea*
				0.249	*Codium reductum*
				0.232	*Udotea indica*
				0.223	*Caulerpa scalpelliformis*
II	7.154	17.9	49.1	0.339	*Melanothamnus somaliensis*
				0.335	*Codium iyengarii*
				0.316	*Caulerpa racemosa*
				0.285	*Ulva rigida*
III	5.991	15.0	64.1	0.292	*Iyengaria stellata*
				0.281	*Stoechospermum marginatum*
				0.279	*Caulerpa veravalensis*
				0.265	*Dictyota indica*

Table 5. Principal component analysis (PCA) of winter 2016 (November to March) of algal assemblages at Sindh coast, Pakistan.

Comp.	Eigen value	% Variance	Cumulative variance %	First four Eigenvector coefficients	Associated species
I	19.905	30.2	30.2	0.210	*Lobophora variegate*
				0.204	*Cystoseira indica*
				0.196	*Dictyota dichotoma*
				0.194	*Sarconema furcellatum*
II	11.272	17.1	47.3	0.258	*Sargassum filifolium*
				0.236	*Sargassum crassifolium*
				0.227	*Dictyota divaricata*
				0.220	*Dictyota indica*
III	10.008	15.2	62.5	0.274	*Codium iyengarii*
				0.253	*Coelarthrum muelleri*
				0.250	*Champia globulifera*
				0.236	*Gelidium folifera*

Principal component analysis (PCA): Principal component analysis is a multivariate technique generally employed to a) data reduction (parsimony), b) revealing trends, c) exposing gradients if any and d) disclosing group structure using the quantitative data i.e., estimates of species within the communities (or sites) and exposing vegetation-environmental relations. The data were analyzed separately for summer and winter seasons of 2016 and are separately discussed below.

PCA ordination for summer season, 2016: The results of principal component analysis (PCA) are given in Table 4 and Figs. 2 & 3. First, second and third principal components explained 31.2, 17.9 and 15.0 percent of the total variance respectively. Together the first three components accounted for 64.1% of the total explained variance. The first component is primarily a function of *Jania capillacea*, *Codium reductum*, *Udotea indica*, *Caulerpa scalpelliformis*. The second principal component is basically controlled by *Melanothamnus somaliensis*, *Codium iyengarii*, *Caulerpa racemosa* and *Ulva rigida*. Whereas the third principal component is chiefly regulated by *Iyengaria stellata*, *Stoechospermum marginatum*, *Caulerpa veravalensis* and *Dictyota indica*.

PCA ordination and Bi plot of the seaweeds: In sampling sites 1, 2 and 3 the score plot (Fig. 3) shows *Chaetomorpha antennia* is the abundant species, while *Polysiphonia adriatica* also available only in sampling sites 1 and 3 (Figs. 2 & 3). These areas are Chach Jaan Khan (Sujawal), Shah bandar (Sujawal) and K.T. Bandar (Thatha), and located in the creeks with dense patches of mangroves in the area. The muddy area provides favorable habitat for Inter-tidal Mudskippers, mangrove forests provide shelter to the coast from sea storm but algae need substratum to grow, therefore, very few species were collected from these sampling points.

In sampling points 4 and 6 which are Manora and Hawksbay, *Caulerpa scalpelliformis*, *Codium indicum*, *Codium reductum*, *Halimeda tuna*, *Udotea indica*, *Ulva fasciata*, *Padina tetrastromatica*, *Coelarthrum muelleri*, *Gelidium folifera*, *Jania capillacea*, *Laurencia obtusa*, *Laurencia pinnatifida*, *Solieria robusta* are abundant species. These areas are mostly comprise of Rocky pools and sandy beaches.

In sampling sitest number 5, 7 and 8 which are Sandspit and Buleji comprises following common species including *Caulerpa taxifolia*, *Caulerpa racemosa*, *Caulerpa chemnitzia*, *Caulerpa veravalensis*, *Codium iyengarii*, *Ulva fasciata*, *Iyengaria stellata*, *Stoechospermum marginatum*, *Coelarthrum muelleri*, *Geladium usmanghanii*, *Jania adherence*, *Jania capillacea* and *Melanothamnus somaliensis* are the common species. While following species are only common between sampling point number 7 and 8 *i.e.*, *Caulerpa scalpelliformis*, *Codium reductum*, *Ulva rigida*, *Gelidium pusillum* and *Laurencia pinnatifida*.

In sampling sitest 9 and 10 which are Sonehra point and Mubarak Village, *Caulerpa taxifolia*, *Caulerpa racemosa*, *Codium iyengarii*, *Ulva rigida Ulva fasciata*, *Sargassum tenerrimum*, *Gelidium pusillum*, *Hypnea musciformis*, *Laurencia pinnatifida* and *Melanothamnus somaliensis* are common and abundant species and *Codium boergesenii*, *Codium indicum*, *Codium reductum*, *Polysiphonia adriatica* and *Jania adherense* are frequent species in these sampling points, both sites represent sandy beaches.

PCA ordination for winter season, 2016: The result of principal component analysis (PCA) are given in Table 5 and Figs. 4 & 5. The first, second and third principal components explain 30.2, 17.1 and 15.2 percent of the total variance. Together the first three components explained 62.5% of the total explained variance. The first component is primarily a function of *Lobophora variegate*, *Cystoseira indica*, *Dictyota dichotoma*, *Sarconema furcellatum*. The second principal component is basically controlled by *Sargassum filifolium*, *Sargassum crassifolium*, *Dictyota divaricata and Dictyota indica*. Whereas the third principal component is chiefly regulated by *Codium iyengarii*, *Coelarthrum muelleri*, *Champia globulifera* and *Gelidium folifera*.

PCA ordination and Bi plot of seaweeds for winter 2016: In sampling points 1, 2 and 3 the score plot shows *Entomorpha flexsousa* was the common and abundant species (Figs. 4 & 5), while *Polysiphonia nizamuddinii* and *Polysiphonia adriatica* also available only in sampling point number 1 and 3. These areas are Chach Jaan Khan (Sujawal), Shah bandar (Sujawal) and K.T.Bandar (Thatha), and located in the creeks with dense patches of mangroves in the area. The muddy area provides favorable habitat for Inter-tidal Mudskippers, mangrove forests provide shelter to the coast from sea storm but algae need substratum to grow so very few species were collected from these sampling points.

In sampling point 9 and 10 which are Sonehra point and Mubarak Village, *Caulerpa racemosa*, *Codium iyengarii*, *Udotea indica*, *Dictyota indica* and *Sargassum vulgare* are common and abundant species and *Caulerpa taxifolia*, *Iyengaria stellata*, *Padina gymnospora*, *Polysiphonia adriatica* and *Halymenia porphyroides* are frequent species in these sampling points, both sites comprises sandy beach.

In sampling point number 4 and 7 which are Manora and Buleji, *Caulerpa faridii*, *Codium iyengarii*, *Halimeda tuna*, *Udotea indica*, *Ulva fasciata*, *Colpomenia sinuosa*, *Cystoseira indica*, *Dictyota dichotoma*, *Dictyota divaricate*, *Dictyota indica*, *Iyengaria nizamudinii*, *Iyengaria stellata*, *Padina gymnospora*, *Padina pavonica*, *Sargassum boveanum*, *Sargassum crassifolium*, *Sargassum filifolium*, *Stypopodium zonale*, *Ahnfeltia plicata*, *Coelarthrum muelleri*, *Halymenia Porphyroides*, *Laurencia obtusa*, *Sarconema furcellatum*, *Solieria robusta* are abundant species. In these areas mostly rocky pools and sandy beaches prevail.

In sampling sites 5 and 6 namely Sandspit and Hawksbay the assemblages comprise of following abundant or common species including *Dictyota divaricate*, *Dictyota flabellate*, *Dictyota indica*, *Iyengaria nizamudinii*, *Iyengaria stellata*, *Padina afaqhussainii*, *Padina gymnospora*, *Sargassum boveanum*, *Sargassum crassifolium*, *Sargassum filifolium*, *Sargassum tenerrimum*, *Sargassum vulgare*, *Stypopodium zonale*, *Halymenia porphyroides*, *Hypnea musciformis.* These sites are also adjacent to each other, therefore, show considerable resemblance in the flora.

The sampling sites 8 (Paradise point) comprises of *Caulerpa faridii*, *Caulerpa chemnitzia*, *Caulerpa veravalensis*, *Udotea indica*, *Colpomenia sinuosa*, *Cystoseira indica*, *Dilophus alternans*, *Iyengaria nizamudinii*, *Iyengaria stellata*. This sites has both rocky and sandy beaches.

Characteristic species of rocky pools are *Caulerpa* spp., *Codium* spp., *Iyengaria* spp., *Cystoseira* spp. *and Dictyota* spp., Those that are generally associated with sandy beaches include *Sargassum* spp., *Padina* spp., *Colpomenia sinuosa*, *Laurencia pinnatifida and Melanothamnus somaliensis.* Muddy habitats are commonly occupied by *Entomorpha flexsousa*, *Chaetomorpha antennia* and *Polysiphonia adriatica*.

Cluster Analysis of seaweeds for summer season: The dendrogram resulting from Ward's cluster analysis is shown in Fig. 6. Six groups could be conveniently extracted. These are characterized below:

Group 1 comprises two Sampling sites 1 and, 3 which are Chach Jaan Khan (Sujawal) and K.T. Bandar (Thatha). In this group *Chaetomorpha antennia*, *Polysiphonia adriatica* are the dominat species organized into communities (Fig. 6).

Group 2 Shah bandar (Sujawal) comprises only one species *Entomorpha flexsousa* which forms pure assemblages (populations).

Group 3 represented sampling Sites 4, 7 and 8 (Manora, Bulei and Paradise point) 11 common species are present *i.e. Caulerpa taxifolia*, *Caulerpa scalpelliformis*, *Caulerpa chemnitzia*, *Caulerpa veravalensis*, *Codium indicum*, *Codium reductum*, *Ulva rigida*, *Ulva fasciata*, *Coelarthrum muelleri*, *Jania capillacea*, *Laurencia pinnatifida* they are organized into assemblages of three or four dominants in terms of IVI.

Group 4 comprises of sampling site 6 (Hawksbay) that is composed of *Caulerpa scalpelliformis*, *Codium indicum*, *Codium reductum*, *Halimeda tuna*, *Udotea indica*, *Ulva fasciata*, *Padina tetrastromatica*, *Coelarthrum muelleri*, *Gelidium folifera*, *Jania capillacea*, *Laurencia obtusa*, *Laurencia pinnatifida*, and *Solieria robusta* as abundants

Group 5 Shows two sampling Sites 5 and 9 (Sandspit and Sonehra point) comprises of nine common species including *Caulerpa taxifolia*, *Caulerpa racemosa*, *Caulerpa veravalensis*, *Codium iyengarii*, *Ulva fasciata*, *Sargassum tenerrimum*, *Hypnea musciformis*, *Jania adherence* and *Melanothamnus* somaliensis. They form communities with generally chlorophytes though *Sargassum tenerrimum* sometimes occurs as the first dominant.

Group 6 consists of sampling Site 10 (Mubarak Village) whwere *Caulerpa taxifolia*, *Caulerpa racemosa*, *Codium iyengarii*, *Ulva rigida Ulva fasciata*, *Sargassum tenerrimum*, *Gelidium pusillum*, *Hypnea musciformis*, *Laurencia pinnatifida* and *Melanothamnus somaliensis* are the abundant species.

Cluster analysis of algae during winter season: The dendrogram derived from cluster for the winter (2016) is given in Fig. 7. Here again six groups (clusters) could be conveniently recognized, their description follows:

Group 1 comprises two Sampling points 1, 3 which are Chach Jaan Khan (Sujawal) and K.T. Bandar (Thatha). In this group *Entomorpha flexsousa*, *Polysiphonia nizamuddinii*, *Polysiphonia adriatica* are the dominants forming a community. Group 2 Shah bandar (Sujawal) comprises only of one species *Entomorpha flexsousa* which is also common in Group 1 but this community is better recognized as a monospecific population.

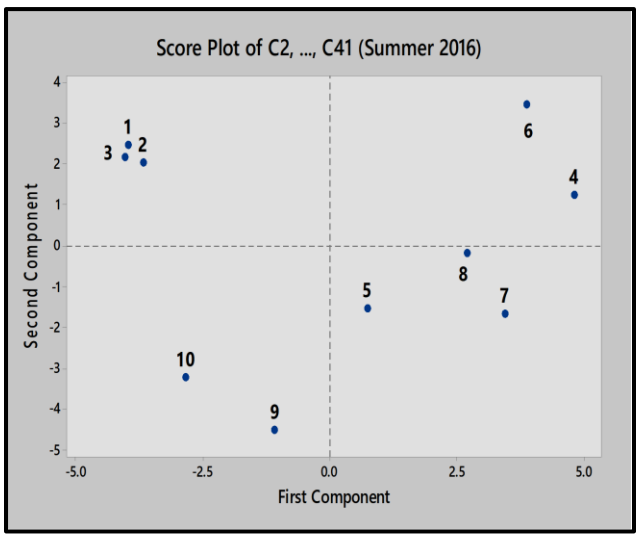

Fig. 2. Score plot of seaweeds data summer season.

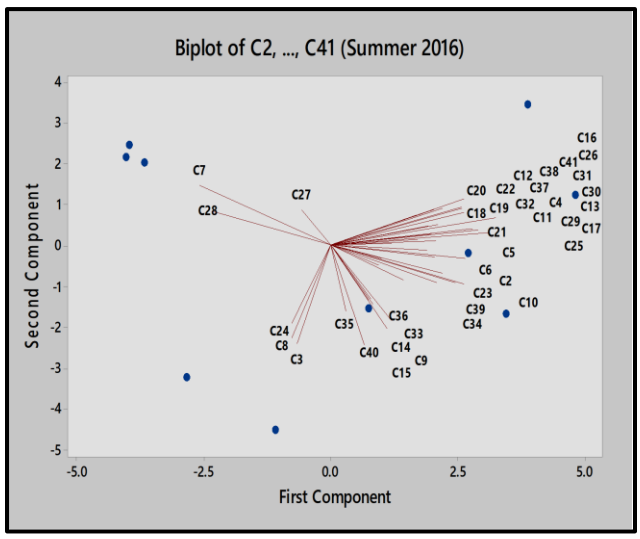

Fig. 3. Bi plot (PCA) of seaweeds data summer season.

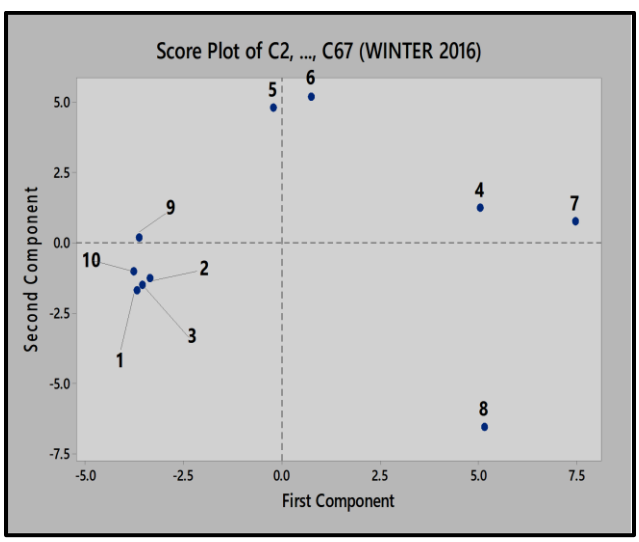

Fig. 4. Score plot of Seaweeds data winter season. Numbers adjacent to points refer to site numbers given in Table 1.

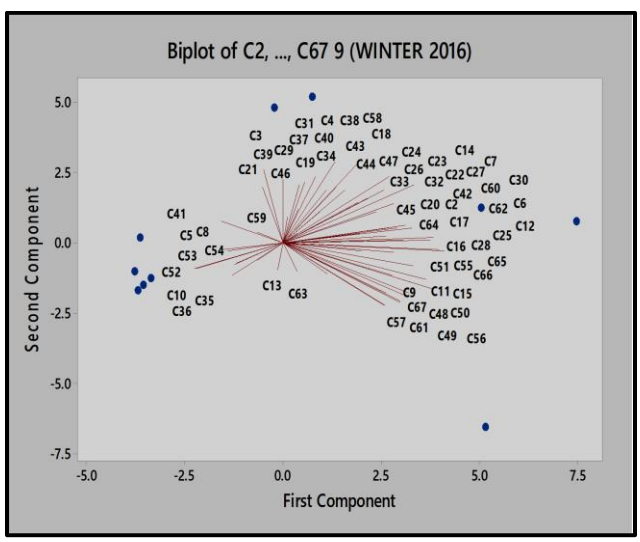

Fig. 5. Bi plot of Seaweeds data for winter season. The numbers against the vectors refer to species numbers given in Table 2.

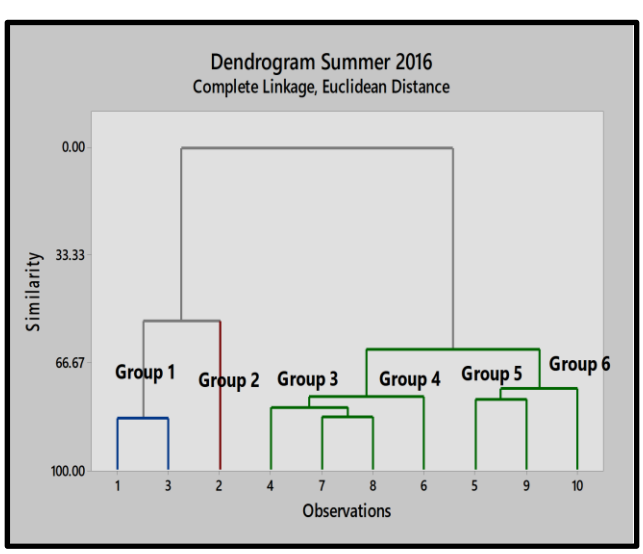

Fig. 6. Dendrogram derived from Ward's clusteri analysis of sites containing seaweed assemblages for summer 2016. Numbers below the bars refer to site numbers given in Table 1.

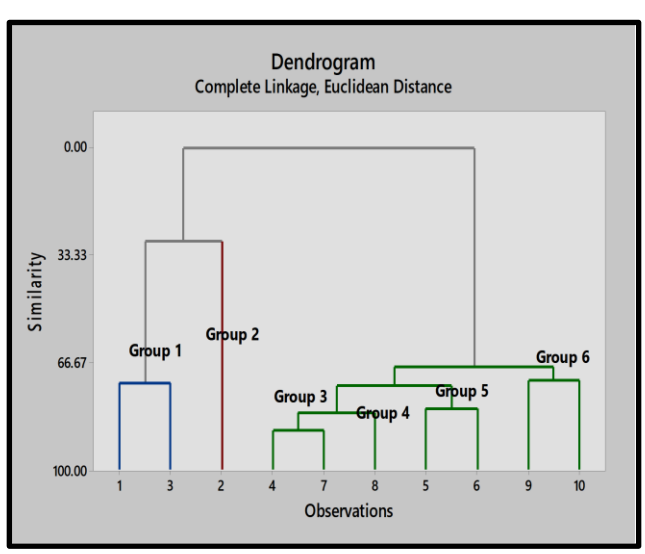

Fig. 7. Dendrogram of seaweeds for winter 2016.

Table 6. Showing monthly presence of seaweeds at the coast of Sindh. Numbers below the bars refer to site numbers.

Groups	F	M	A	M	J	J	A	S	O	N	D	J
Chlorophyta												
Caulerpa faridii	-	-	-	-	-	-	-	-	-	-	+	+
Caulerpa racemosa	-	-	-	-	-	-	-	-	-	+	+	-
Caulerpa scalpelliformis	-	-	-	-	-	-	-	-	-	-	+	+
Caulerpa taxiffolia	+	+	+	-	-	-	-	-	-	-	+	+
Caulerpa veravalensis	-	-	-	-	-	-	-	-	-	-	-	+
Chaetomorpha antennina	-	-	-	-	-	-	+	+	+	-	-	-
Codium iyengarii	+	+	+	-	-	-	-	-	+	+	+	+
Codium latum	-	-	-	+	-	-	-	-	-	-	-	-
Enteromorpha intestinalis	+	-	-	-	-	-	-	-	-	-	-	+
Halmedia tuna	-	+	+	-	-	-	-	-	+	+	-	-
Udotea indica	+	+	-	-	-	-	-	-	-	-	-	+
Ulva fasciata	-	-	-	-	+	+	+	+	+	+	-	-
Ulva rigida	+	-	-	-	-	-	-	-	-	-	-	+
Valoniopsis pachynema	+	-	-	-	-	-	-	-	+	+	+	+
Rhodophyta												
Ahnfeltia spicifera	+	-	-	-	-	-	-	-	+	+	+	+
Botryocladia leptopoda	+	+	-	-	-	-	-	-	-	-	-	-
Ceramium manorense	-	-	-	-	-	-	+	-	-	+	+	+
Champia globulifera	-	-	-	-	-	-	-	-	-	-	-	+
Champia plumose	+	-	-	-	-	-	-	-	-	-	-	+
Coelarthrum muelleri	-	+	+	-	-	-	-	-	-	-	-	-
Galaxaura oblongata	-	-	-	-	-	-	-	-	-	+	+	+
Gelidium folifera	-	-	-	-	-	-	-	+	-	+	+	+
Gelidium usmanghanii	-	-	-	-	-	-	-	-	+	+	-	-
Gracilaria verrucosa	-	-	-	-	-	-	-	-	-	+	-	-
Halymenia Porphyroides	+	-	-	-	-	-	-	-	-	-	+	+
Hypnea musciformis	+	-	-	-	-	-	-	-	-	-	+	+
Jania adherens	-	-	+	-	-	-	-	-	-	-	+	-
Jania caillacea	+	+	+	-	+	+	+	+	+	+	+	+
Laurencia obtuse	+	-	-	-	-	-	-	-	-	-	-	-
Laurencia pinnatifida	-	-	-	-	-	-	+	+	-	+	+	-
Laurencia platyclada	-	-	-	-	-	-	-	-	-	+	-	-
Melanothamnus somaliensis	-	-	-	-	-	-	-	+	-	-	-	-
Sarcodia dichotoma	+	-	+	-	-	-	-	-	-	-	-	-
Sarconema furcellatum	-	-	-	+	-	-	-	-	-	-	-	-
Scinaia indica	+	-	-	-	-	-	-	-	-	-	-	-
Solieria robusta	+	+	+	+	-	-	-	-	-	-	-	-
Phaeophyta												
Colpomenia sinuosa	+	+	-	-	-	-	-	-	+	+	+	+
Colpomenia ecuticulata Parsons	+	+	-	-	-	-	-	-	-	-	-	+
Cystoseira indica	+	-	-	-	-	-	-	-	-	-	+	+
Dictyota dichotoma	+	+	+	-	-	-	-	-	+	+	-	+
Dictyota indica	-	-	-	-	-	-	-	-	+	+	-	-
Dictyota flabellata	+	+	-	-	-	-	-	-	-	-	+	+
Dictyota hauckiana	+	+	-	-	-	-	-	-	-	-	+	+
Dilophus alternans	+	+	-	-	-	-	-	-	-	-	+	+
Iyengaria stellate	+	+	+	-	-	-	-	-	+	+	+	+
Iyengaria nizamudinii	+	+	-	-	-	-	-	-	+	+	+	+
Jolyna laminarioides	-	-	-	-			+	+	-	-	-	-
Lobophora variegate	+	+	-	-	-	-	-	-	-	-	-	-
Padina pavonica	+	+	+	-	-	-	-	-	+	+	+	+
Padina tetrastromatica	+	+	+	-	-	-	-	-	+	+	+	+
Padina afaqhusainii	+	+	+	-	-	-	-	-	+		+	+
Padina antillarum	+	+	+	-	-	-	-	-	-	+	+	+
Padina nizamuddinii	+	+	+	-	-	-	-	-	-	-	+	+
Sargassum boveanum	+	+	-	-	-	-	-	-	-	+	+	+
Sargassum crassifolium	-	-	-	-	-	-	-	-	-	+	+	+
Sargassum filifolium	+	+	-	-	-	-	-	-	-		+	+
Sargassum tenerrimum	+	+	+	-	-	-	-	-	+	+	+	+
Spatoglossum variabile	+	+	+	-	-	-	-	-	+	+	+	+
Spatoglossum qaiserabbasii	+	-	-	-	-	-	-	-	-	-	+	+
Spatoglossum shameelii	+	+	-	-	-	-	-	-	-	-	-	+
Spatoglossum asperum	+	+	+	-	-	-	-	-	-	-	-	-
Stoechospermum marginatum	+	-	-	-	-	-	-	-	+	+	+	+
Stokeyia indica	+	+	+	-	-	-	-	-	-	-	+	+
Stypopodium shameelii Nizamuddin	+	+	-	-	-	-	-	-	-	-	+	+
Stypopodium zonale	+	+	-	-	-	-	-	-	-	-	+	+

Table 7. Monthly variation in the biomass (g/m^2) of seaweeds between the months February (2016) to January (2017) from the coast of Sindh.

Biomasses	F	M	A	M	J	J	A	S	O	N	D	J
Fresh weight (g)	175.2	163.4	115.7	66.3	7.5	6.8	13.2	70.6	94.9	112.4	152.8	168.5
Dry weight (g)	46.4	30.5	28.4	22.5	2.8	2.5	4.4	23.6	27.9	30.4	34.7	39.6

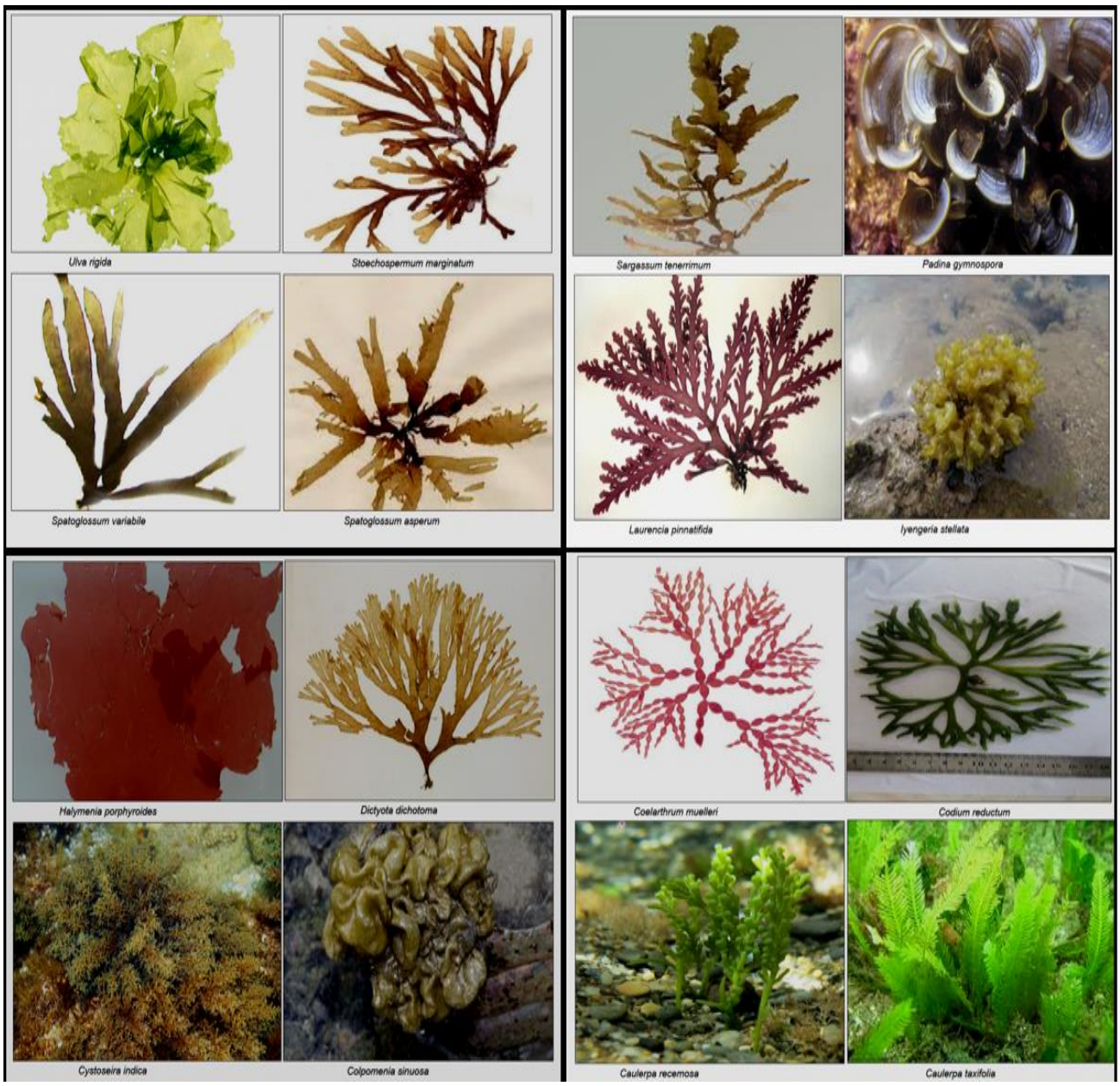

Fig. 8. Showing dominant species throughout the year.

Group 3 represented Sampling Sites 04 and 07 (Manora and Buleji) 37 common species are present *i.e*. *Caulerpa faridii*, *Codium iyengarii*, *Halimeda tuna*, *Udotea indica*, *Ulva fasciata*, *Colpomenia sinuosa*, *Cystoseira indica*, *Dictyota dichotoma*, *Dictyota divaricate*, *Dictyota indica*, *Iyengaria nizamudinii*, *Iyengaria stellata*, *Padina gymnospora*, *Padina pavonica*, *Sargassum boveanum*, *Sargassum crassifolium*, *Sargassum filifolium*, *Stypopodium zonale*, *Ahnfeltia plicata*, *Coelarthrum muelleri*, *Halymenia Porphyroides*, *Laurencia obtusa*, *Sarconema furcellatum*, *Solieria robusta* are abundant.

Group 4 comprises sampling sites number 8 (Paradise point) comprises *Caulerpa faridii*, *Caulerpa chemnitzia*, *Caulerpa veravalensis*, *Udotea indica*, *Colpomenia sinuosa*, *Cystoseira indica*, *Dilophus alternans*, *Iyengaria nizamudinii*, *Iyengaria stellata* are abundant species.

Group 5 Shows two sampling Sites 5 and 6 (Sandspit and Hawksbay) comprises following common species including *Dictyota divaricate*, Dictyota flabellate, *Dictyota indica*, *Iyengaria nizamudinii*, *Iyengaria stellata*, *Padina afaqhussainii*, *Padina gymnospora*, *Sargassum boveanum*, *Sargassum crassifolium*, *Sargassum filifolium*, *Sargassum tenerrimum*, *Sargassum vulgare*, *Stypopodium zonale*, *Halymenia porphyroides*, *Hypnea musciformis.*

Group 6 consists of two sampling Sites 9 and 10 (Sonehra point and Mubarak Village) where the communities are composed of *Caulerpa racemosa*, *Codium iyengarii*, *Udotea indica*, *Dictyota indica* and *Sargassum vulgare* as dominants and well organized into communities with 3 or 4 dominants (in terms of IVI criterion).

Cluster analysis complemented the results of PCA (for both summer and winter data) even though they are employed for achieving different objectives. Such a result has been obtained by other workers as well (Shaukat, 1985; Siddiqui *et al* 2013; see Greig-Smith, 1983; Shaukat and Siddiqui, 2005).

Seasonal biomasses of the dominant seaweed species: Monthly presence of seaweeds at the coast of Sindh shown in Table 6 and the Biomasses of dominant species are given in Tables 7, 8 and Fig. 8. In winter highest masses were found in *Colpomenia sinuosa followed by Dictyota dichotoma*, *Sargassum filifolium and Iyengaria stellata* while in summer highest biomass was observed for *Jania capillacea* followed by *Chaetomorpha antennia* and *Codium reductum*

Table 8. Seasonal biomass of different dominat seaweeds species.

Dominant species	Seasonal biomass	
	Fresh weight (g/m^2)	Dry weight (g/m^2)
2016 (winter)		
Dictyota dichotoma	462	105
Sargassum filifolium	16063	3589.49
Sargassum crassifolium	975.38	157.82
Colpomenia sinuosa	1753.86	216.67
2016 (summer)		
Jania capillacea	1376.85	184.73
Codium reductum	312.56	79.47
Udotea indica	549.81	114.29
Caulerpa scalpelliformis	850.61	128.47

Discussion

The current investigation aimed to provide a quantitative description of the algal flora, their community structure, composition, species richness, and environmental relations with the aid of quantitative sampling and application of principal component analysis (PCA) and cluster analysis (CA). The study also establishes a comprehensive quantitative information on the distribution pattern of marine macroalgae and the seasonal variation over the entire Sindh coastline. Even though, some workers including Saifullah, (1973); Saifullah *et al.*, (1984); Hameed & Ahmed, (1999); Begum & Khatoon, (1988); Nazim *et al.*, (2012) conducted observational studies to estimate the algal growth in different seasons of but their works were restricted only to one locality *i.e.*, Buleji, Karachi.

Multivariate analysis: Wards' agglomerative clustering is employed to extract groups or clusters on an objective basis, avoiding personal bias in recognizing the entities. This method is used to expose the underlying group structure and the associated environmental variables. The groups derived from the different types of coast and the seaweeds were grouped that were allied with different topographic and edaphic conditions. The classification and ordination also disclosed similar information pertaining to environmental relations (Roacky, Sandy and Muddy coast) of the algal assemblages, also exposing the inter-site variation.

Multivariate analysis of seaweed data for summer to winter, 2016: The seasonal algal vegetation showed a significant difference with regard to species composition, abundance and diversity (richness). Within summer season 40 species belonging to different phylum from all over the Sindh coast is observed whereas, cluster analysis of group I that is composed of three stands (Chach jaan khan, Shah bandar and keti bandar) showed only one species that is found in abundance is *Chaetomorpha antenniais*. In case of group II consisting of two sites (Sonehra point and Mubarak Village) observed two species in richness *i.e*., *Caulerpa racemosa* and *Ulva fasciata.* While in group III having two sites (Manora and Paradise point) six species are in abundance including *Codium indicum*, *Codium reductum*, *Caulerpa taxifolia*, *Caulerpa Scaliformis*, *Ulva fasciata*, *Laurencia obtusa.* However, group IV comprised of three sites (Sandspit, Hawksbay and Paradise point) gathered seven abundant species including *Ulva fasciata*, *Caulerpa taxifolia*, *Stoechospermum marginatum*, *Jania capillacea*, *Hypnea musciformis*, *Scinaia filiformis.*

During winter season 66 species of algae was recorded along the Sindh coast. Cluster analysis of group I bore only one species in richness *i.e.*, *Entomorpha flexsousa.* Group II showed two abundant species including *Codium iyengarii* and *Dictyota indica.* Group III possessed twenty species inclusively: *Colpomenia sinuosa*, *Dictyota dichotoma*, *Dictyota indica*, *Dictyota hauckiana*, *Lobophora variegata*, *Sargassum filifolium*, *Sargassum boveanum*, *Sargassum tenerrimum*, *Sargassum vulgare*, *Iyengaria nizamudinii*, *Iyengaria stellata*, *Cystoseira indica*, *Padina pavonica*, *Padina gymnospora*, *Spatoglossum variabile*, *Stypopodium zonale*, *Stokyia indica*, *Halymenia porphyroides*, *Jania adherence.* Group IV consist of fourteen species *i.e*., *Caulerpa taxifolia*, *Udotea indica*, *Cystoseira indica*, *Colpomenia sinuosa*, *Dictyota indica*, *Iyengaria* spp., *Sargassum* spp., *Padina* spp., *Gelidium pusillum*, *Jania adherense*, *Laurencia pinnatifida.*

On comparing the both season it is observed that highest number of species belonging to different phyla found in winter as compare to summer season. However, greater number of algal species belonging to Chlorophyta were seen in summer while in winter Rhodophyta species were in higher quantity. It is evident from Tables 7 and 8 that the greater biomass was produced in winter compared to summer. Highest biomass was depicted by *Sargassum filiformis* followed by *Colpomenia sinosa*. In winter. Wheras, in summerr *Jania capillacea* and *Caulerpa scalpelliformis* prevailed with highest biomass. The lowest biomasses were seen in *Chaetomorpha antennia* and *Dictyota dichotoma.* This is presumably the result of greater photosynthetic rate. This corroborates the finding of Albakistani *et al*., (2021) and Deng *et al*., (2021) that the winter season favours the formation of primary assimilates and secondary metabolites. Higher quantity of these chemical substances photosynthetic products enhances the growth and biomass of algae.

Conclusion

The most species rich site was Buleji (Karachi) with sixty species, while the least number of species were documented from Shah Bandar (Sujawal), i.e., one species. The species richness of seaweeds along the Sindh Coast, their transition and regionalization design along with the appearance of occasional varieties lead us to believe that seaweed strength is highest from November to February and lowest from June to August. The month of February had the highest biomass, while the month of July had the lowest. This information could be valuable in addressing the effective ocean growth resources over the Sindh coastline. The association of various seaweeds to particular habitat or microhabitat conditions was established. The results of cluster analysis and those and the PCA ordination exposed the distribution pattern of species, their associations (assemblages), and the association of seaweeds with particular habitats and microhabitats. The results of the two multivariate techniques complemented each other. By providing data on the ideal growth season, habitats and microhabitats of seaweed development, the current study could also be useful in developing methods to cultivate commercially some economically important seaweeds.

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