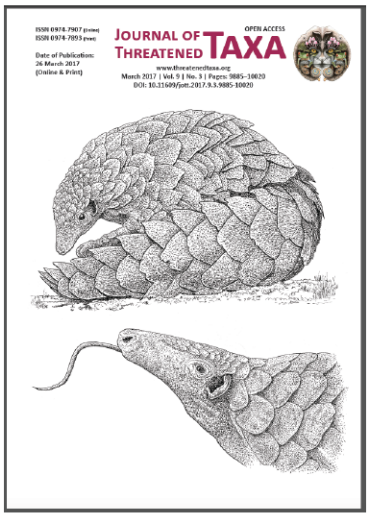

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COMMUNICATION

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Ecology of marine macro algal flora of Visakhapatnam coastal areas, Bay of Bengal, India

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Abstract: An ecological study was conducted on species composition, vertical distribution and monthly variations of marine macro algae along the Visakhapatnam coast, Bay of Bengal, India between May 2013 and April 2014. A total of 48 species was recorded, 18 species belonging to phylum Chlorophyta, nine species to Phaeophyta and 21 species to Rhodophyta. The phylum Rhodophyta was the most dominant group with the highest number of species composition (44.0%) followed by Chlorophyta (37.0%) and Phaeophyta (19.0%). Monthly seaweed distribution data showed the dominance of Rhodophyta members (43.75%) during November to February, when compared to that of Chlorophyta and Phaeophyta members. In addition, the data also revealed that the months from June to August contributed favourable conditions for the growth of Chlorophyta members (29.16%) when compared to that of other months. The present study has recorded two new species (*Ulva lactuca* and *Enteromorpha intestinalis*). Thirty-five species once recorded are absent from the Visakhapatnam coast. These changes are attributed to the impact of marine water pollution and climate change.

Keywords: Intertidal, seasonal variation, seaweeds, species composition, vertical zonation.

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Author's Contribution: The research and preparation of the manuscript was done by IVS, as a part of Ph.D Research, under the supervision of Professor **PSRS**.

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INTRODUCTION

The role of seaweeds in the economic life of humans and ecosystems is relatively well known. The use of algae as food, animal fodder, fertilizers, as raw materials in the production of industrial phycocolloids, and as natural feeds for economically important aquaculture species has received much attention in Thailand and in many other countries around the world such as Japan (Kazutosi et al. 1987), China (Bangmei & Abbott 1987), and other Asian countries (e.g., Korea, Phillipines, India) (Dennis 2003). Basic research on seasonality and ecology of seaweeds provides information on seaweed production and utilization. Seasonal and vertical seaweed community variations in intertidal systems have been driven by such factors as exposure to sun irradiation (Hameed & Ahmed 1999), salinity (Thom 1980), submergence (Arun 1972; Druehl & Green 1982; Luning 1990), tidal factors (Lawson 1957; Reddy et al. 2006), nutrient concentrations (Jhansi & Rarmadas 2009) and water temperatures (McQuaid & Branch 1984).

Vertical zonation is a great ecological concept to study for many reasons, as these studies discuss the species ability to cope with abiotic factors associated with emersion stress, such as desiccation which determines their upper limits, while biotic interactions, e.g., competition with other species sets their lower limits. The intertidal zone is the area of a shore marked by the upper and lower limits of the tide; it is exposed at low tide and immersed at high tide, and exhibits zonation patterns in both plant and animal species. The state of equilibrium for a rocky shore ecosystem can be understood by studying the zonation patterns of flora and fauna for that habitat. As the height above sea level increases, the harshness of conditions in the intertidal zone intensifies; fewer species are able to survive in these conditions (Kaliaperumal et al. 1995), thus species diversity declines with increasing height in intertidal zones. Srinivasan (1959), Misra (1959), Subbaramaiah (1970 & 1971), Agadi & Untawale (1978), and Agadi (1983 & 1985) have described zonation patterns of seaweeds at other coasts of India.

The available literature and research studies during the last five decades on ecological aspects of marine macro algae along the Visakhapatnam coast are available from the research contributions of Rao & Sreeramulu (1964 & 1970) and Rao (1989). The species-wise distribution patterns, composition and seasonal variations of marine algae were reported by Rao et al. (2011). Numerical data with reference to density, dominance and frequency of marine algae was presented by Lakshmi & Rao (2009).

However, the above studies on species documentations with seasonal succession of macro algae from the Visakhapatnam coastline were meagre and need much attention. There has been little attention given to the present status of marine macro algae due to post-industrialization impact at the Visakhapatnam coast with reference to changes in algal species composition and diversity patterns.

Thus the present study was conducted with an overview to notify the changes on the sea weed flora composition and to evaluate the monthly variations in the distribution patterns from the rocky and sandy coasts of the Visakhapatnam coastline. The information collected from this study was compared with earlier studies to find out the species distribution status, composition and succession patterns in vertical zonation.

MATERIALS AND METHODS

Study Area

The study area of the Visakhapatnam coast is located in the northeastern part of the Bay of Bengal, India between 17°15'–18°32'N & 18°54'–83°30'E, which has tropical maritime climatic conditions with prominent seasonal variations. This part of the coastline stretches to a length of 132km, between the two rivers Sarada and Ghostani, encompassed by fringes of the Eastern Ghats abutting into the bay waters.

The Visakhapatnam coastline has two types of shoreline environment: the sandy and rocky shoreline with outcrops of boulders and rocky pools of various sizes protruding into the sea. The other type of shoreline has sandy beaches separated by rocky bottoms and ridges of hillocks. Field surveys were conducted all along the Visakhapatnam coast. Ten sampling sites were established at different locations of the following: Bangarammapalem (S1), Rambilli (S2), Pudimadaka(S3), Appikonda (S4), Yarada (S5), Ramakrishna Beach (S6), Tenneti Park (S7), Rushikonda (S8), Thotlakonda (S9) and Bheemunipatnam (S10) (Fig. 1) and their geo-morphological features and topographical characteristics are provided in Table 1.

Tides on the Visakhapatnam coast are semi-diurnal with two spring tides and two leap tides a day. The littoral currents along the Visakhapatnam coast show a regular change in their magnitude and direction depending upon the direction of the deep sea waves. The average wave period varies from 9–12 seconds for

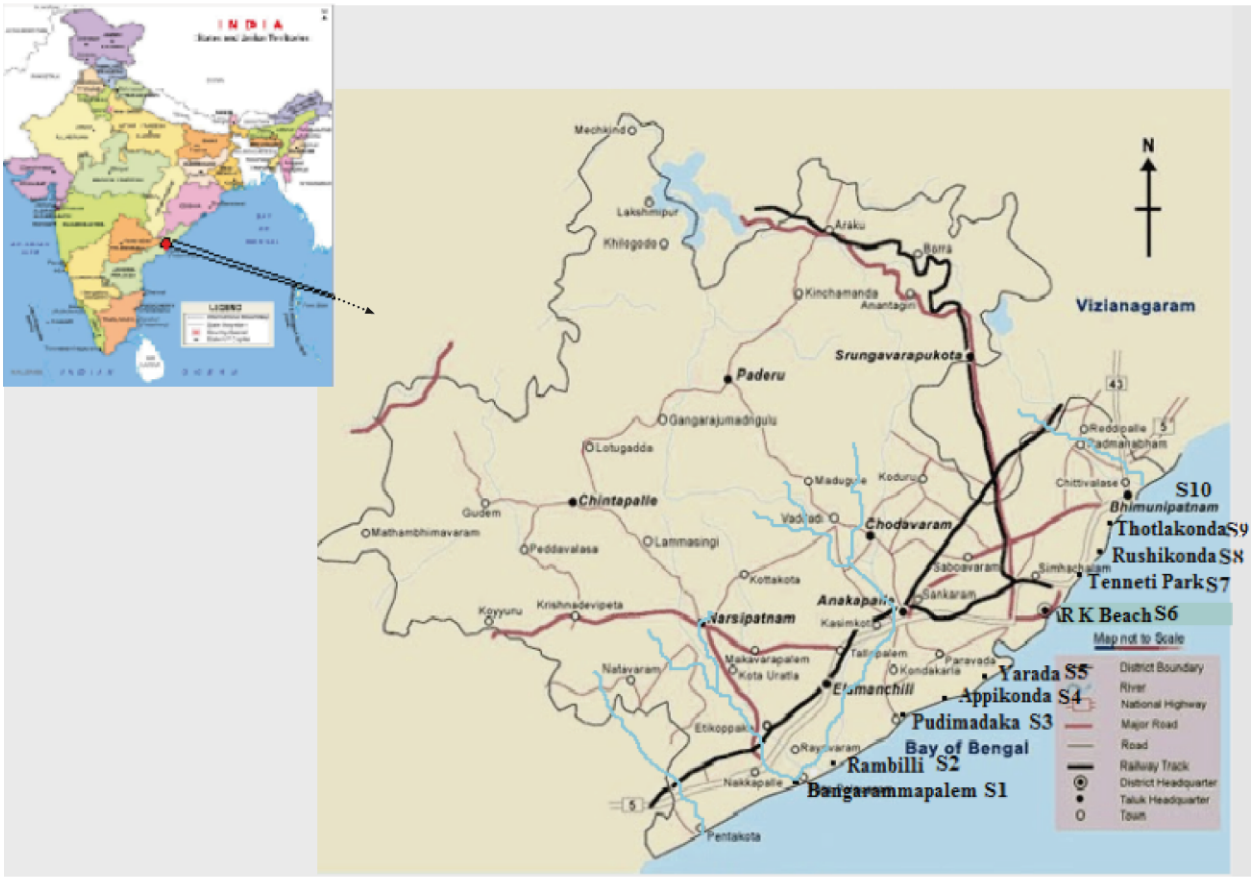

Figure 1. Sampling sites in the present study area.

Table 1. The sampling sites with physical, geo-morphological and topographical features of Visakhapatnam coast

Sampling sites	Physical features of substratum	Geomorphological characteristics	Topograghy of the beaches
S1 - Bangarammapalem	Large boulders	Rocky boulders, pebbles and gravel	Mangrove, sandy & muddy beach
S2 - Rambilli	Boulders	Rocky boulders, pebbles and gravel	Sandy beach
S3- Pudimadaka	Boulders & rocky platforms	Large rocky platform, rook pool ridges	Sandy & muddy beach
S4 - Appikonda	Large boulders	Rocky boulders, pebbles and gravel	Sandy
S5 - Yarada	Rocky area with pools	Rocky platform with small basin like pools	Rocky & sandy
S6- Ramakrishna Beach	Shingles	Shingle area, shoals	Rocky & sandy
S7- Tenneti Park	Rocky platforms with pools	Large rocky platform with small basin pools	Rocky & sandy
S8- Rushikonda	Shingles	Shingle area, shoals	Rocky & sandy
S9- Thotlakonda	Rocky areas with pools	Large rocky platform with tidal pools	Rocky & sandy
S10 - Bheemunipatnam	Boulders & rocky platforms	Large rocky platform with small basin pools	Sandy

most of the year. Tidal data was obtained from Geodetic and Research Branch (G&RB) Survey of India, Dehradun.

Seaweed collection was done by random sampling with a total of 25 quadrants, each 50X50 cm^2 at all field stations at monthly intervals from May 2013 to April 2014. With a view to understand the pattern of zonation, the vertical distribution of the algae on the boulders situated in the intertidal region of the Visakhapatnam coast was examined during the entire period of this study corresponding with the three basic zones (the supra-littoral fringe, the mid-littoral zone and the infra-littoral fringe) of the universal scheme of Stephenson & Stephenson (1949).

The samples were preserved in zip lock plastic bags

after removing the sand particles and other fauna attached to the algae and substratum and all the details like date of sample collection, sediment types and substratum were noted. The collected species were preserved in 5.0% formaldehyde solution. The seaweeds were identified through standard taxonomic keys (Rao & Sreeramulu 1964, 1970; Rao 1989).

RESULTS AND DISCUSSIONS

The occurrence of rich marine macro algae composition in the coastline of Visakhapatnam has contributed to the presence of diversified coastal habitats of varied geomorphological features with the presence of rocky boulders to rocky platforms with tidal pools of different sizes. Another important feature of this coast is the occurrence of monthly variations in the mean tide levels and deposition of sediments at river mouths in some locations especially Bangarammapalem, Pudimadaka and Bheemunipatnam stations. These coastline characteristics at Visakhapatnam influence seasonal and vertical distribution of seaweeds.

A total of 48 seaweed species were recorded belonging to three phyla: 18 species (37%) to Chlorophyta, nine species (19%) to Phaeophyta and 21 species (37%) to Rhodophyta. The monthly distribution pattern indicated Rhodophyta group dominance (Table 2, Fig. 2).

At family level, the highest number of species was represented by Cladophoraceae with eight species, followed by Ulvaceae and Caulerpaceae four species each. In the Phaeophyta group, however, the families Sargassaceae (4 species) and Dictyotaceae (2 species) were dominant. The Rhodophyta contributed the highest number of families with Gracilariaceae (3 species), Rhodomelaceae (2 species) and Liagoraceae (2 species Table 3, Fig. 3). The observations on monthly variations of seaweeds composition exhibit dominance of Chlorophyta members (2.16%) during June to August, whereas, there was a shift of dominance from Chlorophyta to Rhodophyta members (43.75%) in the months from November to February during the study period.

Rao & Sreeramulu (1970) and Rao (1989) reported 80 species of marine algae from Visakhapatnam coast and Lakshmi & Rao (2009) and Rao et al. (2011) recorded 31 and 39 species of macro algae respectively. In contrast to the above findings the present study has recorded 48 species. This indicates a declining trend of 40.0% loss in seaweed diversity and species composition of marine macro algae of the Visakhapatnam coast.

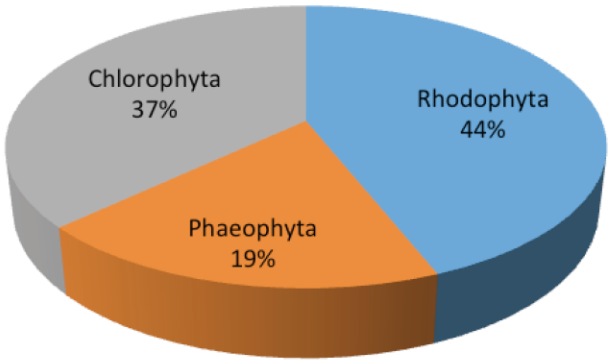

Figure 2. Showing percentage wise dominance of macro algae groups in the study areas of Visakhapatnam coast.

Similar observations were also reported by Lakshmi & Rao (2009) and Rao et al. (2011) for the Visakhapatnam coast; Mukund et al. (2008) for the northwestern coast of India; Kaliaperumal et al. (1995), and Rani et al. (2013) for the Tamil Nadu coast of India. They have delineated that the major cause in the decline of marine algae species and diversity is due to the pollution of the marine water in coastal areas.

Tidal Changes on the Coast

The range of high tides during the study period was observed as 1.03–1.53 m (January 2013 and November 2014 respectively), whereas, range of low tides varied from 0.00–0.49 m (March 2014 and November 2013, respectively). There was a considerable monthly variation in the spring and leap tide levels on this coast, since the mean tide levels and mean sea level varies from month to month.

From the curves it was clear that the duration of submergence was high in two periods, one in June with an increase from May and the other in October–November with an increase from September. Minimum submergence was observed in the month of February. The submergence values per tide at any point on the shore were somewhat higher in 2014 than that of 2013. Yearly variations of leap and spring tide levels are evident from the graph given in Fig. 4. During winter months the percentage emersion was less when the temperature fell to the minimum.

Seasonal Observations on Seaweeds

The present study observations revealed that regeneration of seaweed groups with dominance of Chlorophyta members was in the months of May and June. Then again from July to September there was a fall in Chlorophyta growth, in addition to a gradual increase

Table 2. Occurrence and monthly distribution of marine macro algae at Visakhapatnam coast.

	Family	Seaweeds (Scientific names)	Monthly Observations											
			2013								2014			
			M	J	J	A	S	O	N	D	J	F	M	A
Chlorophyta														
1	**Ulvaceae**	*Ulva fasciata*	+	+	+	+	+	+	+	+	+	+	+	+
2		*Ulva lactuca*	+	+	+	+	+	-	-	-	-	-	-	-
3		*Entermorpha compressa*	+	+	+	+	+	+	+	+	+	+	+	+
4		*Entermorpha intestinalis*	+	+	+	+	+	+	-	-	-	-	-	-
5	**Cladophoraceae**	*Chaetomorpha antennina*	-	-	-	+	+	+	+	+	+	+	+	+
6		*Chaetomorpha brachygona*	-	-	-	-	-	+	+	+	+	+	-	-
7		*Chatemorpha torta*	-	-	-	-	-	+	+	+	+	+	-	-
8		*Cladophora socialis*	+	+	+	+	+	+	+	+	+	+	+	+
9		*Cladophora utriculosa*	-	-	-	-	-	-	+	+	+	+	+	+
10		*Cladophora fasicularis*	+	+	+	-	-	-	-	-	-	-	+	+
1		*Cladophora colabense*	+	+	+	-	-	-	-	-	-	-	+	+
12		*Boodlea struveoides*	+	+	+	+	+	+	+	+	+	+	+	+
13	**Ulotrichaceae**	*Spongomorpha indica*	+	+	+	+	+	+	+	+	+	+	+	+
14	**Bryopsidaceae**	*Bryopsis pennata*	+	+	+	+	+	+	+	+	+	+	+	+
15	**Caulerpaceae**	*Caulerpa fastigata*	+	+	+	+	+	+	+	+	+	+	+	+
16		*Caulerpa racemosa*	+	+	+	+	+	+	+	+	+	+	+	+
17		*Caulerpa taxifolia*	+	+	+	+	+	+	+	+	+	+	+	+
18		*Caulerpa sertularioides*	+	+	+	+	+	+	+	+	+	+	+	+
Phaeophyta														
19	**Ectocarpaceae**	*Ectocarpus mitchellae*	-	-	-	-	-	-	+	+	+	+	+	+
20	**Scytosiphonaceae**	*Chnoospora minima*	+	-	-	-	-	-	+	+	+	+	+	+
21	**Dictyotaceae**	*Dictyota dichotoma*	-	-	-	-	-	-	+	+	+	+	+	+
22		*Padina tetrastromatica*	+	+	+	+	+	+	+	+	+	+	+	+
23	**Sargassaceae**	*Sargassum vulgare*	-	-	-	-	+	+	+	+	+	+	+	+
24		*Sargassum ilicifolium*	+	+	+	+	+	+	+	+	+	+	+	+
25		*Sargasssum polycestum*	-	-	-	-	+	+	+	+	+	+	+	+
26		*Sargassum tenerrium*	-	-	-	-	+	+	+	+	+	+	+	+
27	**Acinetosporaceae**	*Giffordia indica*	+	+	+	+	+	+	+	+	+	+	+	+
Rhodophyta														
28	**Bangiaceae**	*Porphyra vietnamensis*	-	-	-	-	-	+	+	+	+	+	-	-
29	**Stylonemataceae**	*Bangiopsis subsimplex*	-	-	-	-	-	-	+	+	+	+	+	+
30	**Lomentariaceae**	*Gelidiopsis variabilis*	+	+	+	+	+	+	+	+	+	+	+	+
31	**Gelidiaceae**	*Gelidium pusillum*	+	+	+	+	+	+	+	+	+	+	+	+
32	**Pterocladiaceae**	*Petrocladia heteroplatos*	+	+	+	+	+	+	+	+	+	+	+	+
33	**Corallinaceae**	*Amphiroa fragilissima*	-	-	-	+	+	+	+	+	+	+	+	+
34		*Jania rubens*	-	-	-	-	-	+	+	+	+	+	+	+
35	**Halymeniaceae**	*Grateloupia lithophila*	+	+	+	+	+	+	+	+	+	+	+	+
36		*Grateloupia filicina*	+	+	+	+	+	+	+	+	+	+	+	+
37	**Gracilariaceae**	*Gracilaria corticata*	+	+	+	+	+	+	+	+	+	+	+	+
38		*Gracilaria textori*	+	+	+	+	+	+	+	+	+	+	+	+
39		*Gracilaria edulis*	-	-	-	-	-	-	+	+	+	+	-	-

	Family	Seaweeds (Scientific names)	Monthly Observations											
			2013								2014			
			M	J	J	A	S	O	N	D	J	F	M	A
40	Cystocloniaceae	*Hypnea valentiae*	+	+	+	+	+	+	+	+	+	+	+	+
41		*Hypnea musciformis*	-	-	-	-	-	-	+	+	+	+	-	-
42	Gigartinaceae	*Gigartina acicularis*	-	-	-	-	-	-	+	+	+	+	+	+
43	Liagoraceae	*Liagora visakhapatnamensis*	-	-	-	-	-	-	+	+	+	+	+	+
44		*Liagora erecta*	-	-	-	-	-	-	+	+	+	+	+	+
45	Ceramiaceae	*Centroceros clavulatum*	-	-	-	-	+	+	+	+	+	+	+	+
46	Rhodomelaceae	*Bryocladia thwaitesis*	-	-	-	-	+	+	+	+	+	+	+	+
47		*Acanthophora spicifera*	-	-	-	-	-	-	+	+	+	+	+	+
48	Wrangeliaceae	*Wrangelia argus*	-	-	-	-	-	-	+	+	+	+	+	+

+ = present; - = absent

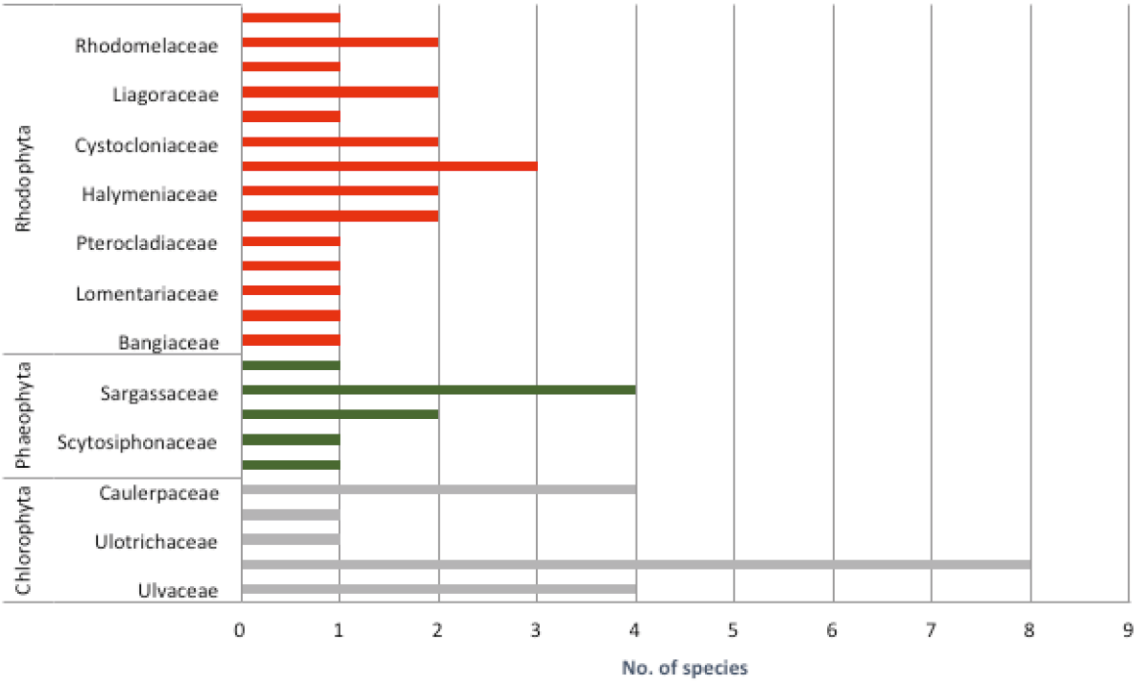

Figure 3. Family-wise species composition of marine macro algae at Visakhapatnam coast

of Rhodophyta members. Another luxuriant crop with many Rhodophyta members along with green algae such as *Chaetomorpha antennina* and *Enteromorpha compressa* occurred from the month of November to February, followed by gradual degeneration in all seaweed forms in March and by April many of them disappeared.

The present study observations were supported with the earlier studies findings at Visakhapatnam coast by Rao & Sreeramulu (1964); at Karnataka coast by Agadi (1985); at Goa coast by Agadi & Untawale (1978); at Gujarat by Gopalakrishnan (1970); and at Philippines by Gavino & Teresita (1987) which indicated the existence of a regular seasonal succession with maximum growth of red algae in the months from November to March. These changes of growth in different algal forms are predominant due to changes in submergence duration and wave actions. Similar seasonal variations were recorded for macro algal diversity in mangrove ecosystems at Zhanjiang, China by Zhang et al. (2014).

Table 3. Number of families and species of marine algae recorded from Visakhapatnam coast.

	Locality	Chlorophyta		Phaeophyta		Rhodophyta		Total	
		Families	Species	Families	Species	Families	Species	Families	Species
1	Bangarammapalem	04	04	-	-	03	03	07	07
2	Rambilli	05	09	03	04	09	10	17	23
3	Pudimadaka	05	16	05	08	14	21	24	46
4	Appikonda	01	01	-	-	02	02	03	03
5	Yarada	05	15	05	09	13	17	23	40
6	Ramakrishna Beach	05	12	03	06	13	17	21	35
7	Tenneti Park	05	12	04	06	13	17	22	35
8	Rushikonda	05	11	03	04	12	16	21	31
9	Thotlakonda	05	17	05	08	14	20	24	44
10	Bheemunipatnam	05	12	04	08	14	17	23	37

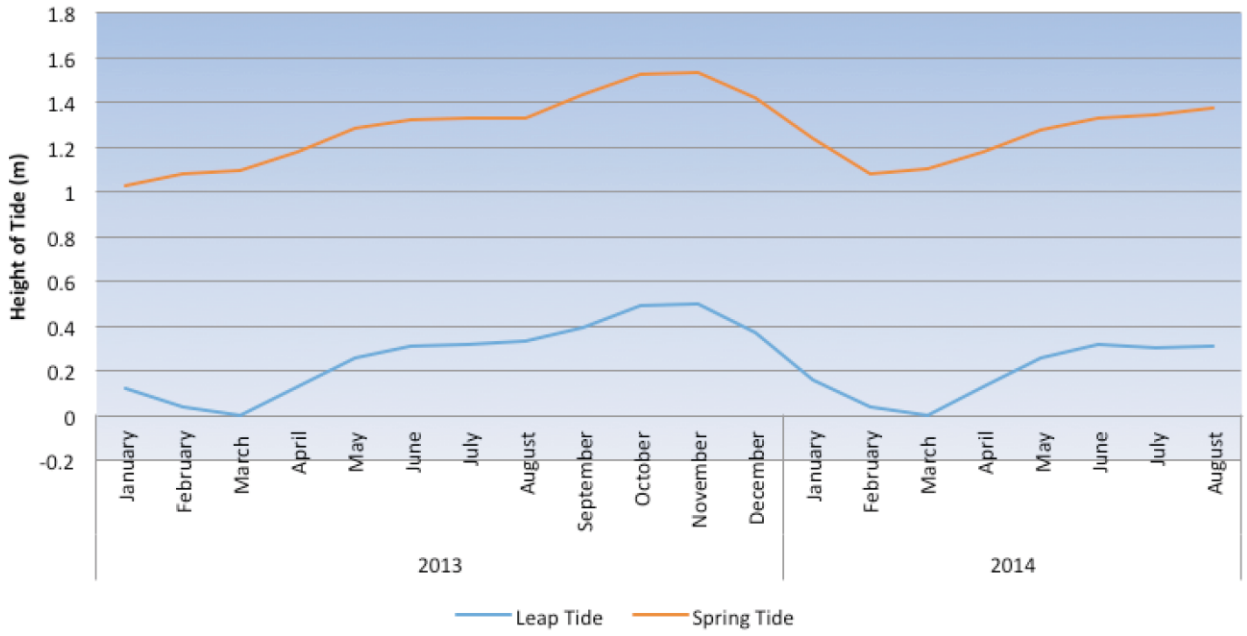

Figure 4. Graph representing tidal data of Visakhapatnam coast during the study period

Nair et al. (1990) observed that brown algal density increased during the monsoon, i.e., in the months of July to September in the southwestern coast of India. But this observation is quite contrary to the one obtained in the present study, where algal distribution decreased during the monsoon.

Vertical Distribution of Seaweeds

The vertical distribution of macroalgal species at each zone in the study area is given in Table 4. Vertical zonation was not clearly distinguished in the three field stations (Bangarammapalem, Appikonda and Rushikonda) on this coast line. On this coast, the supra-littoral fringe is present only in some field stations (Pudimadaka, Yarada, R.K Beach, Tenneti Park and Thotlakonda), where rocks stand high enough for its formation. In these stations *Ulva fasciata, Enteromorpha intestinalis* and *Chaetomorpha antennina* were rarely observed in the supra-littoral zone.

There is a wide highly visible mid-littoral zone, with dominant seaweeds all along the coast. *Ulva fasciata, Chaetomorpha antennina, Spongomorpha indica, Amphiroa fragilissima* are dominant algae of this zone and these algae generally form regular bands each year in the periods of their maximum development.

On this coast, infra-littoral fringe is characterised by

Table 4. Algal zonation observations at Visakhapatnam coast

Supralittoral fringe	Midlittoral zone	Infralittoral zone
Ulva fasciata *Enteromorpha intestinalis* *Chaetomorpha antennina*	*Ulva fasciata* *Ulva lactuca* *Enteromorpha compressa* *Enteromorpha intestinalis* *Chaetomorpha antennina* *Chaetomorpha brachygonia* *Chaetomorpha torta* *Cladophora socialis* *Cladophora utriculosa* *Cladophora fasicularis* *Spongomorpha indica* *Bryopsis pennata* *Ectocarpus mitchellae* *Chnoospora minima* *Porphyra vietnamensis* *Bangiopsis subsimplex* *Petrocladia heteroplatos* *Amphiroa fragilissima* *Gigartina acicularis* *Liagora erecta* *Centroceros clavulatum* *Bryocladia thwaitesis* *Acanthophora spicifera* *Wrangelia argus*	*Ulva fasciata* *Chaetomorpha brachygonia* *Spongomorpha indica* *Bryopsis pennata* *Caulerpa fastigata* *Caulerpa racemosa* *Caulerpa taxifolia* *Caulerpa sertularioides* *Dictyota dichotoma* *Padina tetrastromatica* *Sargassum vulgare* *Sargassum ilicifolium* *Sargasssum polycestum* *Sargassum tenerrium* *Gelidiopsis variabilis* *Gelidium pusillum* *Jania rubens* *Grateloupia lithophila* *Grateloupia filicina* *Gracilaria corticata* *Gracilaria textori* *Gracilaria edulis* *Hypnea valentiae* *Hypnea musciformis* *Centroceros clavulatum* *Wrangelia argus*

the occurrence of dominant *Gracilaria* and *Sargassum* band forming perennials with a clear cut break in the vegetation at the upper limit. Along with the above species *Centroceros clavulatum, Jania rubens, Spongomorpha indica* and *Dictyota dichotoma* also form scattered algal turfs in places.

Kaliaperumal et al. (1995) suggested most seaweed species were observed in depths from 5.5–17 m revealing that certain species are widely distributed along vertical gradient of coasts. Agadi & Untawale (1978) and Agadi (1983) observed vertical gradients along the Goa coast of species of *Chaetomorpha, Ulva* and *Enteromorpha* occurring at higher levels on rocks exposed to light where only humidity is required for algal growth. Similar observations were made along the Visakhapatnam coast. Misra (1959), however, had observed Ulva and Enteromorpha belts in the upper mid-littoral zone.

The nature of distribution of the species occupying different intertidal levels is attributable to their ability to endure the varying conditions of the intertidal zone with the ceaseless cycles of submergence and emergence and the associated wash, splash and spray (Balakrishnan et al. 1990; Russell 1991; Chapman 1995). The Sargassum species are found at the infra-littoral zone, whereas *Padina tetrastromatica* is found in both mid and infra littoral zones of the Visakhapatnam coast. These species show similar zonation patterns at Anjidiv Island, a small Arabian Sea Island (Arun 1972). Species of *Caulerpa, Padina, Hypnea* and *Centroceras clavulatum* are common inhabitants of infra-littoral fringe zones of Madapam coast (Rao & Sreeramulu 1970).

This confirms that certain seaweed species follow similar zonation patterns at different coasts. The seasonal changes in the algae observed in this study in relation to the variations in the exposure and submergence and other factors further confirms that the seasonal tidal behaviour and other changes in the physical conditions of the marine environment brought about by monsoons are responsible for the fluctuations in the growth and abundance of the intertidal algae as suggested by Deborah et al. (2007) and Rao (1970).

CONCLUSION

The seasonal and vertical changes in the growth of macro algae at the intertidal region of the Visakhapatnam coast from May 2013 to April 2014 were studied and discussed. According to the present study the highest number of species was recorded at Pudimadaka (46 species) followed by Thotlakonda (44 species), whereas the lowest number of species was reported from Appikonda (03 species). Observations on the ecology of seaweed flora of Visakhapatnam, their distribution and zonation pattern with seasonal variations lead us to conclude that there is a high dominance of seaweed richness at the infra-littoral zone during November to February. This data was helpful in knowing the potential quantitative seaweed resources at different field stations of the Visakhapatnam coast. This study can be further used in farming of economically important seaweeds, by providing information on the ideal conditions of seaweed production.

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