Temporal effect on the abundance and diversity of intertidal rocky shore macroalgae

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A study of the temporal effect on the abundance and diversity of intertidal rocky shore macroalgae revealed that there are ~70 species in the intertidal rocky shore of Anjuna (60 species) and Vagator (52 species) in Goa, India. Results showed that pre-monsoon (May) and post-monsoon (December) seasons favoured high species richness and abundance in both the study sites. In both cases, species diversity was low during the monsoon months (July and August). The study showed that low diversity might be a monsoonal effect and it coincides with the growth of *Ulva* and *Porphyra* species. The growth of opportunistic annuals brings about an ephemeral dominance of the macroalgal community by annual macroalgae. The driver is believed to be the nutrient influx from surface run-off, change in salinity and temperature due to high precipitation. The study showed that monsoon could have a role on the macroalgal community dynamics, and there was a strong correlation between diversity and biomass.

Keywords: Biomass, monsoon, microalgal abundance and diversity, nutrient run-off.

THE intertidal rocky region, despite its barren appearance, is teeming with life and macroalgae are one of the main constituents. They form the basis of the trophic structure and support numerous associated faunas in the form of food and refuge. As a primary producer, their diversity and abundance have the ability to transform and determine the characteristics of the community structure in a rocky shore ecosystem. However, the habitat disturbance due to anthropogenic activities has been the major cause of biodiversity decline in the oceans, including intertidal rocky shore biodiversity[1].

Macroalgae are a dynamic community and exhibit a spatial and temporal variation in terms of species richness and composition. There is evidence of a latitudinal biodiversity gradient in the marine system, where areas of low and high species richness have been identified throughout the temperate and tropical waters[2]. Macroalgal numbers are, however, negatively correlated to elevation with fewer species in the higher zones[3]. The processes and the effect on the alteration of macroalgal biodiversity have been alluded to habitat destruction, disease, overexploitation[4], population depletion and trophic cascade[5], coral bleaching and macroalgal recovery[6], habitat transformation and opportunist proliferation[7], eutrophication[8] and grazing effect of the grazers[4,9,10]. The intertidal zone is also exposed to harsh conditions which cause sudden mortality, but they also increase diversity or reduce species diversity under certain circumstances[2,11].

Macroalgae play a major structural and functional role in several habitats ranging from turfs to kelp forest[10]. They are widely recognized ecosystem engineers[12] or foundation species[13], and an important carbon sink[14]. So the changes in composition of the macroalgal community through habitat loss/modification or climate change will affect the ecosystem[10]. Macroalgal communities are also critical for the recruitment and protection of many economically important fish and shellfish fisheries[15]. Macroalgae also serve as a valuable bioindicator because they respond rapidly to environmental changes in the coastal ecosystem[16].

Community of healthy biodiversity is believed to have better ecosystem performance. The diversity of organisms potentially influences both bottom-up (nutrient uptake and production) and top-down (grazing and predation) processes; diverse producer assemblages are more effective at using limiting nutrients[17]. This study aims at understanding the temporal effect of monsoon on the diversity and abundance of intertidal macroalgae in Anjuna and Vagator, Goa, India.

Stratified sampling was done from the intertidal rocky shore of Anjuna (15°48′00″N, 74°20′13″E) and Vagator (15°35′53″N, 73°44′41″E) beaches, through a quadrat (0.25 m^2) method. Sampling was done monthly over a period of three years (March 2012–December 2014) covering all the seasons. Analysis of the data showed that the abundance and distribution followed a similar trend. Therefore, data were normalized to measure the temporal abundance and diversity. Samplings were carried out during low tide (tide levels 0.1–5 m) and samples were collected in triplicate. Macroalgal samples were cleaned and sorted manually in the laboratory. Macroalgae were identified following the available taxonomic keys[18–21] and quantified for statistical purpose. Algae were oven-dried at 60°C for 48 h until constant weight was obtained to measure biomass.

Data were analysed on the basis of seasons: pre-monsoon (February–May), monsoon (June–September) and post-monsoon (October–January) using PRIMER 6 software. Macroalgal abundance data were used to analyse the Shannon–Weiner diversity index (H'), Margalef's species richness (d) and Peilou's evenness (j') in PRIMER#6.

Bray–Curtis similarity at 50% similarity was performed to determine the similarity in the macroalgal temporal abundance and diversity. Normality of the data was checked by Kolmogorv–Smirnov and Lilliefors test and the data were standardized, wherever required, prior to analysis. One-way ANOVA was used to measure the temporal effect on the macroalgal species richness and

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Table 1. Temporal variation in ecological macroalgal community indices from the two study sites

Site	Community indices*	Pre-monsoon (February–May)	Monsoon (June–September)	Post-monsoon (October–January)
Anjuna	Richness (*d*)	7.88	2.87	4.4
	Evenness (*j*′)	0.87	0.71	0.82
	Diversity (*H*′)	3.39	2.43	0.94
	Species	48	30	39
Vagator	Richness (*d*)	6.77	5.55	7.09
	Evenness (*j*′)	0.82	0.75	0.75
	Diversity (*H*′)	3.05	2.61	2.82
	Species	41	33	42

**d*, Margalef species richness; *j*′, Pielou's eveness; *H*′, Shannon–Wiener diversity index.

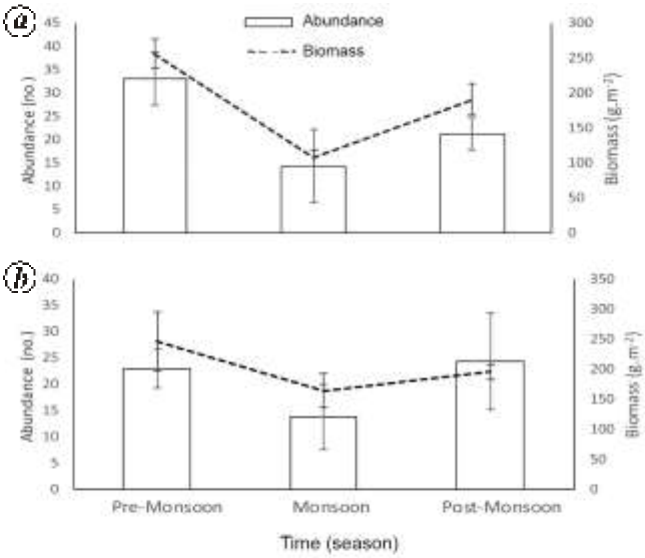

Figure 1. Temporal variation in the macroalgal abundance and biomass (dry weight) from the intertidal rocky shore of (***a***) Anjuna and (***b***) Vagator, Goa, India.

abundance. Post-hoc Tukey test was performed when there was significance. Similarity in macroalgal vegetation between the two study sites was determined using Czekanowski coefficient[22] $C = 2w/a + b$, where w is the number of taxa common at both sites, a the number of taxa at one site and b the number of taxa at the second site.

Altogether 70 macroalgae species were recorded from the intertidal rocky shores of Anjuna and Vagator (Supplementary Table 1). Of these, Anjuna was more diverse with 61 species and Vagator recorded a total of 54 species. Overall, 17 species belong to green algae (Chlorophyta), 16 to brown algae (Phaeophyta) and 37 to red algae (Rhodophyta). Czekanowski coefficient showed that the two study sites shared 73% floristic similarity.

Results showed that high diversity, richness and evenness indices of macroalgal distribution were recorded during pre-monsoon and post-monsoon seasons, according to macroalgal community indices in both Anjuna and Vagator intertidal sites (Table 1 and Figure 1 *a* and *b*). Monsoon recorded the least diversity indices in both sites. One-way ANOVA showed a significant temporal effect on the macroalgal species richness and abundance in both Anjuna ($P < 0.001$) and Vagator ($P < 0.001$) sites. During monsoon months, *Ulva compressa*, *Ulva flexuosa*, *Ulva fasciata* and *Porphyra* species were dominant. Data analysis showed that *U. flexuosa*, *U. fasciata* and *Porphyra* species were evenly distributed, but the abundance was markedly more in Anjuna. However, the dominance varied temporally depending on the development phase (Supplementary Table 2).

Similar to biodiversity indices, macroalgal biomass was high during pre-monsoon and post-monsoon in both sites (Figure 1 *a* and *b*); it was low during monsoon. Cluster analysis at 50% similarity also revealed that pre-monsoon and post-monsoon seasons formed one cluster, whereas monsoon formed another unit (Figure 2 *a* and *b*).

Record of earlier studies revealed 74 macroalgal species, and a recent report[23] has shown a record of 146 macroalgae species from the coast of Goa. The present study showed that intertidal rocky shores of Anjuna and Vagator have ~48% of the recorded species. Results showed a strong temporal influence on the macroalgal abundance and diversity. The diversity and abundance was least during monsoon months, whereas post-monsoon and pre-monsoon months revealed rich diversity. The high correlation in cluster dendrogram corroborated this observation. Macroalgal diversity was high in Anjuna rocky site compared to Vagator. High diversity during pre-monsoon and post-monsoon was attributed to greater light intensity, which results in increased photosynthesis and growth[24]. Monsoon is reported to support a scanty growth of few species confined to supralittoral zone[25].

The study further showed that low diversity during July and August could be a monsoon-induced effect. Low diversity period also coincided with a spurt in the growth of *U. flexuosa*, *U. fasciata* and *Porphyra* species. These annual algae form a mat-like growth in the mid and high intertidal rocky region causing an ephemeral dominance, a monsoonal characteristic observed during the study. The effect of monsoon is inversely proportional to the macroalgal diversity. This suggests that the fast-growing annual algae take advantage of the change in the ecosystem.

During the period, high nutrient input takes place due to surface run-off and freshwater influx[26,27]. The overall nutrient concentration increases considerably by up to 46% during monsoon[27], accompanied by change in salinity and temperature due to high precipitation. *Ulva* species have broad tolerance range to factors like salinity, temperature and nutrients[28]; similar is the case with *Porphyra*[29,30]. Therefore, the dominance and vigorous growth of *Ulva* and *Porphyra* is probably due to the prevailing environmental conditions. The even distribution of *Ulva* species also indicated their adaptability to transient condition. The study also showed that the dominance among macroalgae species varies temporally which stretches over to the next season depending on the development phase.

Macroalgal zoospore are known to undergo dormancy during unfavourable conditions and survive under adverse conditions[31–33]. Presumably, the composite blend of fine sediment and decayed macroalgal biomass forms a protective jacket to the dormant zoospores that will serve as a propagule bank for recruitment. This process ensures the perpetuation of the population on return of an ambient environmental condition, annually. The regular occurrence of dense mat of filamentous green algae on the tidal flat of Koningshafen Bay (Island Sylt, North Sea, Federal Republic of Germany) was due to overwintering of adult plants or fragments[34]. Another factor for low diversity in monsoon months could be the strong current and wave action that dislodges the macroalgae from the substratum. The breaking-off is mostly due to the anastomizing habit of the algal fronds[25]. The overall diversity may also be affected by the grazers, although the grazing effect has not been dealt with in the present study. Increasing abundance of grazers and overgrazing leads to loss of dominant habitat-forming species[35]. However, the Czekanowski coefficient revealed 73% floristic similarity between the two sites indicating a rich macroalgal diversity. The difference in the diversity between the two sites could be due to local conditions.

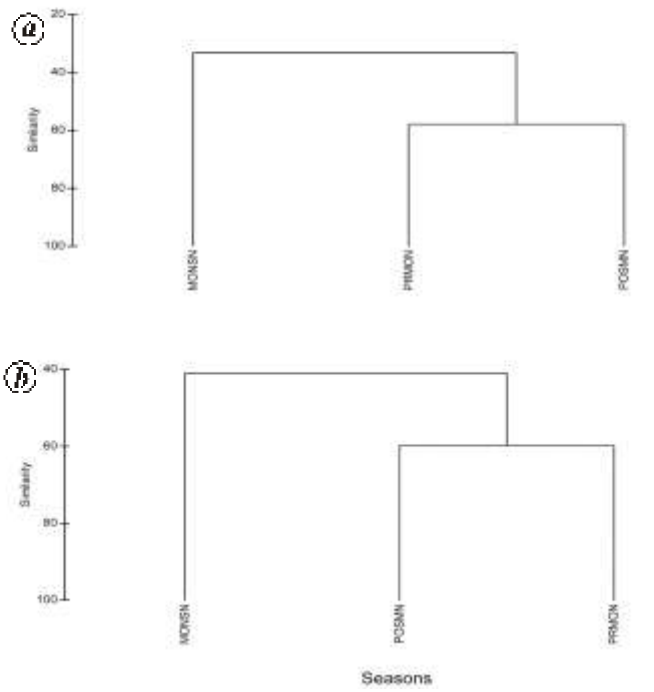

Figure 2. Cluster dendrogram of the seasons based on macroalgal abundance and diversity at 50% similarity from the intertidal rocky shore of (***a***) Anjuna and (***b***) Vagator. MONSN, Monsoon; POSMN, Post-monsoon, PRMON, Pre-monsoon.

The present study showed a positive correlation between species richness and biomass. An earlier study also showed that algal biomass increased during pre-monsoon period[36]. In concurrence with the present study, several other reports showed positive correlation between macroalgal biomass and species richness: wetland ecosystem[37], soft sediment benthic system[38], temperate marine ecosystem and intertidal zones in the northern hemisphere[2]. However, it was not positively correlated when examined in a larger spatial scale, i.e. latitude stating that complementarity of diversity and biomass fits better in smaller spatial scale[2]. The biomass and species composition of macroalgae largely depend upon season and other ecological factors[39]. However, due to observational limitations, establishing a causal relationship and identification of the underlying mechanism are not possible[40].

The study also showed that monsoon could be a major driver to the dynamics of macroalgal community structure by influencing the characteristics in terms of abundance and species diversity. Similarly, microlocal condition could be another reason that might have influenced the diversity characteristics between the two sites. The results of this study offer a baseline for future monitoring. However, temporal effects of monsoon on the spatial distribution need to be investigated in future.

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