RESEARCH COMMUNICATIONS

15. Hartl, G., At use of an annual value of US $18 billion, and occurs widely on temperate and tropical rocky shores throughout the world.1,2. Nearl
species of Porphyra have been reported from all over the world and they occupy diverse spatial and temporal habitats\(^1\). Its life cycle consists of alternation of macroscopic gametophytic stage with microscopic conchocelis stage\(^1\). It is not only delicious, but also contains high levels of protein (25–50%), vitamins (vitamin C is higher than that in oranges), trace minerals and dietary fibres\(^5\). Porphyra has been cultivated for the past 100 years in Japan, Korea and China\(^6\). Because of its economic importance and other health benefits, Porphyra cultivation is now being expanded to other countries\(^7\). Seven species have been recorded from the Indian coast. However, these are not being exploited commercially\(^3\).

The occurrence of Porphyra on the Indian peninsular region was first reported from Karachi\(^8\) as Porphyra vulgaris C.Ag., followed by two species, Porphyra lunciata (Lightf.) Ag. and P. vulgaris C.Ag., recorded from Ceylon\(^9\). Along the Indian coast, leafy phase of Porphyra vietnamensis reported from Vishakapatnam coast, is a summer annual (April/May), while the same species occurs on the Goa coast during active monsoon (July/October), showing peak growth in August. Porphyra okhaensis sp. nov. from Okha is a winter annual occurring during November–January\(^10\). Porphyra kanyakumarensis Krishnamurthy et Baluswamy grows during the southwest monsoon, July–September, along the Kerala coast\(^11\).

Growth of P. vietnamensis during monsoon is one of the most conspicuous features along the west coast of India. This alga grows profusely in magenta coloured mats over the entire rocky surfaces in the upper littoral zone\(^12\). The thalli are membranous, undulate with spinulose processes along the margins\(^13\). A number of studies reveal that each stage in the life cycle of Porphyra is species-specific and dependent on light, temperature and photoperiod\(^14\).

The aim of this study was to identify the causal factors that lead to the variation in growth patterns of this alga. The growth and development of alga was monitored over a four-month period to note changes in distribution, abundance, biomass and other characters for better understanding of the seasonal and differential growth patterns of Porphyra.

Fortnightly collections of littoral seaweeds were carried out at three sites along the Goa coast (Figure 1). Two sites (Dona Paula and Reis Magos) with estuarine influence of Zuari and Mandovi river respectively, and (Vagator) open coast were selected for seaweed collection. The distribution and relative abundance of P. vietnamensis were recorded at each station. For qualitative studies, a line transect was laid perpendicular to the coast and seaweeds were sampled in triplicate using 0.25 m\(^2\) quadrat. The collected seaweeds were carefully sorted, cleaned to remove extraneous matter such as epiphytes, shells, sand particles, etc., weighed and expressed as kg m\(^{-2}\) (wet weight). In order to find the relation between length and biomass of P. vietnamensis, lengths of 20 thalli of this alga were measured at each sampling at all the three sites. The biomass and thallus measurements of alga (length) were taken as indicators of growth.

Data on sea water nutrients such as NO\(_3\), NO\(_2\) and PO\(_4\) at three different sites were analysed according to the Strickland and Parsons method\(^15\) and are presented in Figure 2. Temperature, pH, dissolved oxygen and salinity records are shown in Figure 3. Rainfall data were obtained from the Panaji observatory of the India Meteorology Department, Goa (Table 1). The correlation coefficient (\(r\)) between physicochemical parameters and biomass was calculated using Microsoft excel software program and the significance level (\(P\)) was ascertained according to the Fischer's statistics book\(^16\).

Studies undertaken on the monsoon annual of P. vietnamensis along the west coast of India and Sonkhla Province, southern Thailand, indicate that this species occurs during rainy season and cooler parts of the year, when the sea temperature and salinity are low\(^12,17\). It has been pointed out in culture studies that low temperature and short days are suitable factors for growth of Porphyra thalli; this response corresponded with the observed seasonal behaviour of plants in nature\(^18\).

Dhargalkar et al.\(^12\) observed that high rainfall influenced the growth of Porphyra (peak biomass was 1.6 kg m\(^{-2}\)), due to reduced salinity (3.5‰) and low temperature (25°C). Decline in rainfall levels led to increased salinity and temperature, and hence a marked decline in biomass. We observed that the three sites showed different growth levels of this alga. Maximum biomass of Porphyra recorded at Vagator was 1.3 kg m\(^{-2}\) in the first fortnight of August followed by Dona Paula (0.9 kg m\(^{-2}\)) and Reis Magos (0.5 kg m\(^{-2}\)) in the second fortnight of August (Figure 4). Highest biomass coincided with the lowest temperature and shorter sunshine hours (Table 1). Also, maximum species of seaweeds associated with Porphyra were found at Vagator. The thalli of Porphyra were relatively well developed at
Vagator. This is supported by positive as well as significant correlation between the length of the thallus and its biomass \((r = 0.839, P < 0.01; r = 0.785, P < 0.02\) at Vagator and Dona Paula respectively). A similar relationship was observed between length and biomass of *Asparagopsis delilei* Montagne at Putty island \((r = 0.812, P < 0.001)\) and Valai island \((r = 0.699, P < 0.01)\), located in the Gulf of Mannar\(^{19}\). There have been published generalizations regarding the connection of the mass with linear body size and of the mass with intensity of certain biological functions\(^{20}\).

At Vagator, highest phosphate concentration \((5.88 \mu\text{mol} \text{L}^{-1})\) corresponded with highest biomass of the season \((1.3 \text{ kg m}^{-2})\), whereas at Dona Paula and Reis Magos, rainfall, temperature and salinity were found to affect algal growth. Moreover, the difference in salinities at these estuarine systems due to some geological features, like the width of the river mouth and sand bar formation at the mouth of the Mandovi estuary during the monsoon months could be a cause for lower salinity at Reis Magos \((2.78–33.62\‰)\), compared to the slightly higher salinity at Dona Paula \((3.06–34.17\‰)\). Lower temperature was found to be conducive for the growth of *P. vietnamensis*. This is supported by a negative and significant correlation with biomass at Reis Magos \((r = –0.83, P < 0.01)\), Vagator \((r = –0.81, P < 0.01)\) and Dona Paula \((r = –0.6, P < 0.1)\). A similar relationship was observed in

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**Figure 2.** Nutrient concentration at three sites during the study period.

**Figure 3.** Physico-chemical parameters of water during the study period.
Table 1. Meteorological data of the locality during the study period

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Figure 4. Biomass of Porphyra vietnamensis at different sites during the study period.

Figure 5. N : P ratio at three different sites.

the intertidal populations ($r = -0.536$) of A. delilei from the Mandapam region$^{21}$. These differences in salinities could be the causative factor for the differences in biomass.

Various studies conducted on this alga indicate that the parameters responsible for its growth remain more or less constant. A study made on Porphyra leucosticta Thuret in Le Jolis, from southern Mediterranean coast of Spain, showed that leafy thallus occurs only during winter (mid-December to mid-March), with peak cover in February$^{22}$. Thus its disappearance coincides with increasing day length, high irradiance and sea water temperature. The conchospore formation and release in Porphyra spiralis var. amplifolia Olle vera Filho et Coll. from warm, temperate coast of southern Brazil, is controlled by a combination of short days along with varying range of temperatures$^{23}$.

Variation in nitrate and phosphate concentration of the Mandovi–Zuari estuarine system from that of the open ocean may be due to addition of nitrogenous material in the former from land and river run-off$^{24}$. The seasonality in nutrient limitation of marine macro algal growth is a well-known phenomenon$^{25}$. The positive correlation observed between the biomass (fresh weight) of Porphyra and phosphate concentration ($r = 0.772$, $P < 0.01$) at Vagator, indicates that phosphate rather than nitrate is a growth-limiting factor. Vagator exhibited higher level of phosphate compared to nitrate. Hence, lower ratio of nitrate and phosphate corresponded with higher biomass at Vagator (Figure 5).

Even though nitrogen is believed to be the primary nutrient limiting factor, evidence suggests that phosphorus may commonly be the primary limiting nutrient to algal growth in certain waters. The results of in situ macro algal bioassays in Florida reveal that inorganic phosphorus was quantitatively more important than nitrogen in limiting both photosynthetic capacity and growth of Gracilaria tikvahiae Mac Lachlan$^{26}$. These studies, however, contrast with temperate North American shore waters where nitrogen is considered the primary nutrient limiting growth factor for macro algae$^{27}$.

The decline in biomass of P. vietnamensis towards the end of September is marked by the discoloration of its thalli. This could be due to decrease of nutrient, and increase in salinity and water temperature$^{28}$. This progressive disappearance of thalli is linked with increased temperature and day length. Although senescence is largely unknown in algae, it is probably an important physiological process in those algae with alternations of generations. Thus, it can be said that there exists a relationship between senescence and phosphorus limited growth, as seen at the end of the life cycle of P. leucosticta$^{29}$.

Umamaheshwara Rao and Sreeramulu$^{30}$ pointed out that the seasonal growth period in which Porphyra flourishes
luxuriantly on the coast is around the period when most of the algal forms growing in that region are in a degenerating condition. However, at Vagator, Porphyra and other seaweeds, Enteromorpha flexuosa, Gelidium pusillum (Stackh.) Le Jolis and Ulva fasciata Delile showed a more or less equal proportion. The abundant growth of seaweeds at Vagator could be due to the fact that open shore plants have higher biomass than those growing in an inlet 31.

Field observations showed that Porphyra entities were restricted in their distribution to particular parts of the intertidal and upper littoral zones. The relative abundance of sub-strata suitable for Porphyra attachment varied among the sites. The sites also differed in degree of water movement, tidal emersion characteristic and topography 31. Therefore, these factors are presumably important in recruitment, survival, growth and development of P. vietnamensis, and hence population structure at each site differs. It appears that the dominant parameters influencing the growth of Porphyra are nutrients (particularly phosphate at Vagator, \( r = 0.77, P < 0.01 \)) and temperature (\( r = -0.81, P < 0.01 \) at Vagator; \( r = -0.83, P < 0.01 \) at Reis Magos, and \( r = -0.6, P < 0.1 \) at Dona Paula). A more detailed study needs to be made in order to pinpoint the precise causative factor.