Growth and phenology of red alga *Gracilaria verrucosa* (Huds.) Papenf.

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Two peak seasons were observed for elongation growth of *G. verrucosa* with a primary peak in January and February, and a secondary peak in September. All three phases of life cycle of alga were found to occur in nature. Tetrasporic and cystocarpic phases were found almost throughout the year and spermatangial plants were observed only from February to April. Mixed plants with tetrasporangia and cystocarps were also recorded.

Growth and phenology of *Gracilaria* species growing on the Indian coast have been reported. However, except for the observations made by Ahmed on *Gracilaria verrucosa* from Chilka Lake, no other information is available. In the present paper, growth and phenology of *G. verrucosa* collected from the coast of Beyt Island, Gujarat are reported.

**Materials and Methods**

Beyt Island is situated between lat. 22°25' - 22°28'N and long. 69°5' - 69°9'E about 5 km off southeastern side of Port Okha. On the 3 km sandy coastal strip situated on the northwestern side of the island, *G. verrucosa* occurs at 0 to 0.1 m level above zero of the chart datum. The alga is sparsely attached to shells and buried often under the sandy habitat.

Monthly (February 1986 - January 1987) random samples of 15 plants of *G. verrucosa* were collected during spring tides. Length of primary shoot was recorded. Simultaneously, 50 plants were collected randomly for phenological observations. Number of tetrasporic, cystocarpic, spermatangial and vegetative plants were recorded. Based on these data, the relative frequency of vegetative and reproductive plants was calculated.

Meteorological data were obtained from the meteorological observatories of Port Okha and Ahmedabad. Period of exposure between 0 and 0.1 m level above zero of chart datum was calculated adopting standard method.

**Results**

Data on climatic conditions of Beyt Island are given in Fig. 1. Gradual increase in maximum and minimum air temperatures is registered from January to June, and thereafter, there is gradual decline (Fig. 1A). Monsoon season at the Beyt Island is from June to August reaching a peak during July (Fig. 1B). Gradual increase in wind speed is registered from February to July, reaching a peak in July. During monsoon months, the high wind speed results in rough sea conditions. After July, gradual decline in wind speed is registered, reaching minimum in October (Fig. 1C).

Seasonal variation in mean length of *G. verrucosa* is shown in Fig. 2. Gradual decline in length of alga was observed from February to May. Thereafter, the mean length increased showing 2 peak seasons,

![Fig. 1—Monthly variation in climatic conditions at Okha](image-url)
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viz. primary peak in January and secondary peak in September (Fig. 2). During July and August the plants were not exposed during lowest spring or neap tides.

Fig. 3 shows the seasonal variation in the frequency length distribution of *G. verrucosa*. Gradual increase in frequency class A was observed from February to June. Simultaneously, gradual decline was observed in frequency classes B and C. During January, comparatively high occurrence of frequency classes B and C (40% each) and 10% of A and D resulted in the primary peak growth of the alga (62.7 cm mean length). The secondary peak (50.44 cm mean length) during September resulted due to high occurrence (54%) of frequency class B and simultaneous occurrence of frequency class A (28%), C (8%), D (6%) and E (4%).

All 4 phases, viz, tetrasporic, cystocarpic, spermogonial and vegetative plants, were observed in samples collected (Fig. 4 A to D). Peak tetrasporic phase (78%) was observed during February (Fig. 4 A). Thereafter, as a result of increase in seawater temperature and maturation and liberation of tetraspores, a decline in tetrasporic phase was recorded (Fig. 4 A). Cystocarpic phase of *G. verrucosa* also occurred throughout the year except in monsoon, July/August, (Fig. 4B). Two peaks were observed, one in May and the other in January. Gradual increase in cystocarpic phase was observed from February to May and September to January (Fig. 4B). The spermatangial phase was of short span from February to April at very low percentage frequency of occurrence. During the rest of the year, no spermatangial plants were observed (Fig. 4 C). Few mixed phases of plants with cystocarpic and tetrasporic phases were observed during January-February.
The tetrasporic phase was found on the main thallus, while side branches developed from main tetrasporic branch showed number of cystocarps.

Increase in seawater temperature from February to June (Fig. 5 B) resulted in decline in mean length of *G. verrucosa* (Fig. 2), reaching lowest in May and June during peak seawater temperature of summer months. At the same time, tidal exposure was comparatively more (2 h for mean 4-7 d in a month, Fig. 5 A). Increase in seawater temperature coupled with longer exposure period during summer months (Fig. 5) may be responsible for the decline in mean length of *G. verrucosa* from March to June (Fig. 2). On the other hand, decline in seawater temperature from September to December/January (Fig. 5 B) correlated with an increase in mean length of *G. verrucosa* during these months, reaching primary peak in January (Fig. 2), when the seawater temperature was low (Fig. 5 B). The tidal exposure was either nil or moderately low from September to January (Fig. 5 A).

Observations on fruiting behaviour of *G. verrucosa* (Fig. 4) and seawater temperature (Fig. 5 B) suggest that during lowest seawater temperature in February, the percentage occurrence of tetrasporic phase was maximum (85%). As seawater temperature increases from March to June, decline in occurrence of tetrasporic phase was observed. While during the same period, the percentage occurrence of cystocarpic phase was enhanced. This might be due to occurrence of spermatangial phase during February to April, which might be resulting into fertilization and development of cystocarps. Possibly due to same reason, the percentage occurrence of cystocarpic phase was more or less the same as in March to June (Fig. 4 B).

Table 1 shows results on the growth and phenology of *G. verrucosa* at Beyt Island and other species of *Gracilaria* occurring at different localities on Indian coast. Comparison of data shows that on different localities of Indian coast, most species of *Gracilaria* exhibit 2 peak seasons of growth, primary peak occurring in November/December to January/February and secondary peak in June/July to August/September (Table 1). However, unimodal growth cycle in a year has also been reported in *G. arcuata var. arcuata*, and *G. corticata var. cylindrica* from Kilakkarai coast\(^5\). Similar observations have been reported in *G. foliifera*\(^2\) from the Mandapam coast. The extent of these seasons, however, depend upon prevailing environmental parameters like topography of the coast, exposure period and prevailing seawater temperature condition.

**Discussion**

Natural population of *G. verrucosa* growing at Beyt Island occurs throughout the year with bimodal half yearly growth cycle. Further the maximum number of young plants occur in May-June and October-November and they grow to maximum size within 4-5 months of growth period. Thus young plants of October/November grow to maximum size in January/February during primary peak season and young plants of May/June grow to maximum size in September/October during secondary peak season.

Predominance of sexual plants over asexual in members of Gigartinales and Cryptonemiales was
Table 1—Growth and phenology of species of *Gracilaria* in India

<table>
<thead>
<tr>
<th>Species</th>
<th>Locality</th>
<th>Growth Period</th>
<th>Period of maximum growth</th>
<th>Tetrasporic</th>
<th>Cystocarpic</th>
<th>Spermatangial</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Gracilariopsis</em></td>
<td>Mandapam</td>
<td>Jan.-May</td>
<td>April</td>
<td>Jan.-May</td>
<td>Jan.-March &amp; May</td>
<td>Chennubhotla et al.²</td>
<td></td>
</tr>
<tr>
<td><em>G. textorii</em></td>
<td>Chilka Lake</td>
<td>Oct.-June</td>
<td>April</td>
<td>April</td>
<td>Dec.-June</td>
<td>NR</td>
<td>Ahmed¹</td>
</tr>
</tbody>
</table>

NR = Not reported

recorded⁶. Contrary to this, observation on *G. verrucosa* from Beyt Island, showed more abundance of tetrasporic plants than sexual plants (Fig. 4). Similar observations were made in *G. corticata* from Veraval¹, in *G. foliifera*, *G. edulis* and *Gracilariopsis sjoestedtii* from Rameshwaram coast⁷, in *G. corticata* and *G. textorii* from Visakhapatnam coast⁸,⁹, and in *G. foliifera* from Kilakkarai². Absence of spermatangial thalli was reported in *G. verrucosa* from Chilka Lake³ and *Gracilariopsis sjoestedtii* from Rameshwaram coast⁷. However, in the present study low percentage of spermatangial thalli was found from February to April (Fig. 4) as reported among many other members of Gigartinales¹,⁷,¹⁰. Mshigeni¹² related the above phenomena to spore size, density and faster sinking rate. Faster sinking rate offered ecological advantage to the bigger spores. In the present study, like in many other members of Florideophyceae, carpospores were slightly bigger in size (mean 34 μm diam.) than tetraspores (mean males during early development stages, and the shorter period of fertility of males¹¹. An unequal representation of different phases of the same species from different places was also mentioned by Fritsch⁶.

Moreover, at Beyt Island in *G. verrucosa*, tetrasporic and cystocarpic phases occurred almost throughout the year (Fig. 4), with predominance of tetrasporic phase. Similar observations were recorded in other members of Gigartinales¹,⁷,¹⁰. Mshigeni¹² related the above phenomena to spore size, density and faster sinking rate. Faster sinking rate offered ecological advantage to the bigger spores. In the present study, like in many other members of Florideophyceae, carpospores were slightly bigger in size (mean 34 μm diam.) than tetraspores (mean...
26 μm diam.), which could have caused preponderance of tetrasporic phase over cystocarpic phase in *G. verrucosa*. Moreover, Hansen and Doyle\(^\text{13}\) suggested from population studies of red alga *Iridaea cordata* (Turner) Bory, that observed dominance of tetrasporophytes over gametophytes is an adaptive response of the life history phase. These workers further suggested that this disproportionality may occur in an environment where majority of tetraspores are unable to germinate and establish gametophytic phase, a plausible explanation for observed fruiting behaviour of *G. verrucosa* at Beyt Island. In addition, carposporophytes were more susceptible to decay than tetrasporophytes\(^\text{14}\). In comparison, after shedding tetraspores, the tetrasporophytes cause defoliation and the defoliated branches resume growth quickly in the beginning of winter.

Occurrence of mixed phases were reported in a number of species of *Gracilaria*. Boergesen\(^\text{15}\) reported occurrence of spermatangial sori on tetrasporic thallus in *G. millardetii*. Later, Ohmi\(^\text{16}\) reported similar observations in *G. bladergetii*, *G. bursapastoris* and *Gracilariopsis vermiculophylla* from the Japanese coast. In Indian species of *Gracilaria*, Umamaheswara Rao\(^\text{17}\) reported occurrence of spermatangial sori on tetrasporic ramulai of *G. verrucosa* from Krusadai Island. In the present study also mixed phases of tetrasporophyte and carposporophyte were observed. Occurrence of mixed phases may be due to germination of tetraspores *in situ*\(^\text{15}\) or genetic recombinations of somatic cells in tetrasporophyte\(^\text{16}\) or due to mutation\(^\text{18}\).

Occurrence of three phases in the population suggests that normal triphasic ‘*Polysiphonia* type’ of life history exists in *G. verrucosa*, as demonstrated *in vitro* by Ogata *et al.*\(^\text{21}\). However, the pattern of life history in anomalous plants of *G. verrucosa* showing mixed phases, may possibly differ, and may not follow the same triphasic ‘*Polysiphonia* type’. Detailed laboratory culture, hybridization and genetic studies are very much needed to explain such irregularities in Indian species of *Gracilaria*.

**Acknowledgement**

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**References**

19. Van der Meer J P, (Personal communication).