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Phenology of *Chondrus ocellatus* in Cheongsapo near Busan, Korea

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Abstract

The reproductive phenology of *Chondrus ocellatus* and the effects of temperature and light on its growth were examined in Cheongsapo near Busan, Korea, from September 1994 to August 1995. The vegetative plants dominated over the year, with a peak occurrence in January. Gameto- and tetrasporophytes were most abundant in November and August. All vegetative and reproductive plants had a peak both in length and weight in October, when seawater temperature was highest (24 °C). In laboratory culture, the maximum relative growth rate (RGR) of 2.94% day^{-1} was obtained at 20 °C and 100 μmol photons m^{-2} s^{-1}, whereas the lowest value was recorded at 25 °C and 100 μmol photons m^{-2} s^{-1} in a 12: 12 h LD photoperiod regime. Among the three photoperiod regimes (8:16 h, 12:12 h, 16:8 h LD) tested, there was evidence of a higher RGR in the 12:12 h LD cycle. This result suggests that the growth and reproduction of *C. ocellatus* are correlated with the seawater temperature based on laboratory culture and field observations.

Introduction

The genus *Chondrus* Stackhouse, which is widely distributed in temperate and cold-temperate waters (Lüning, 1985), has long been used as a source of gelling and stabilizing agent in foods (Taylor & Chen, 1994). Because of its commercial importance, there have been numerous studies on the genus to elucidate its biology and ecology (see Taylor & Chen, 1994). However, most studies have been based on Irish moss, *Chondrus crispus* Stackhouse. *Chondrus ocellatus* Holmes is mainly distributed on the coasts of Korea, Japan, China and Taiwan (Taylor & Chen, 1994). Although there are several reports on the life history, morphology and growth of this species (Ji & Guo, 1992; Brodie et al., 1993; Li et al., 1994), little is known about its phenology of growth and reproduction. In Korea, *C. ocellatus* inhabits the lower intertidal zone and is abundant on moderately exposed rocky shores (Kang, 1968). Recently, Choi and Kim (1999) reported that carrageenans from the Korean species have valuable anticoagulant properties.

Thus, the aim of this study was to investigate the reproductive phenology of *C. ocellatus,* in Cheongsapo near Busan in Korea, as baseline information for its management in the future. The present work provides new information on seasonal patterns in the proportions of reproductive phases and the sizes of individual thalli, in *C. ocellatus.* In addition, the effects of temperature and light on its growth are also examined in laboratory culture to compare with field observations.

Materials and methods

Cheongsapo is on the south eastern coast of Busan (129°12′E, 35°9′N), Korea. This site has a shallow and gently sloping intertidal zone. *Chondrus ocellatus* was sampled monthly from September 1994 to August 1995. Fifty fronds were randomly collected on the rocks of sampling areas, including rock pools, at each time. Plants were transported to the laboratory, then sorted by reproductive status (i.e. vegetative, gametophytic or tetrasporic), using visual examination and confirmation under a microscope. The occurrence of each reproductive stage was expressed as a percentage of the total number of plants analyzed. The length and fresh weight of each plant was measured after it had been rinsed in tap water, drained, and blotted.

Single apices of 5 mm length were excised from the plants and their growth evaluated in an experimental matrix (after a 24 h acclimatization period) under temperatures of 15, 20 and 25 °C and 40, 60 and 100 μmol photons $m^{-2}\ s^{-1}$ at 12:12 LD photoperiod regime. Apical segments were cultured at 15 °C and 60 μmol photons $m^{-2}\ s^{-1}$ at three photoperiod regimes (8:16 LD, 12:12 LD and 16:8 LD) for 60 days. Irradiance was measured using a Li-Cor Model Li-1400 quantum meter. For each condition, 30 segments were individually weighed and inoculated into a culture vessel containing 200 ml of culture medium (PES) (Provasoli, 1968). Media were changed every seven days. Each treatment was replicated 3 times. The relative growth rate (RGR) using fresh weight data was calculated for each replicate according to the following formula:

$$RGR = \ln(W_t / W_0)t^{-1} \times 100$$

where W_0 is initial wet weight and W_t is the wet weight after t days. The seawater temperature data were obtained from NFRDI (National Fisheries Research and Development Institute).

Statistical analyses were performed using STATISTICA v. 5.0. A two-way ANOVA was used to test the effects of temperature and irradiance on the RGR of *Chondrus ocellatus*. A one-way ANOVA was applied to examine the effect of photoperiod in the RGR of the species. When significant differences between treatments were detected, the Tukey test was applied (Sokal & Rohlf, 1995).

Results

Monthly seawater temperature varied from 11 °C in March to 24 °C in September during the study period (Figure 1). Vegetative, gametophytic and tetrasporic plants were found in fluctuating ratios throughout the year (Figure 2). Vegetative plants were relatively abundant compare to reproductive plants during the entire study (above 36%) peaking in January (60%) with a minimum in November and August (36%). Maximum abundance of reproductive plants including both gameto- and tetrasporophytes was observed in November and August (64%) while minimum values were found in January (40%). Gametophytes were most abundant from September to December (30–40%), when temperature and daylength decreased. By contrast, tetrasporophytes were relatively abundant in other months, particularly, from April to August (36–44%), when temperature and daylength increased.

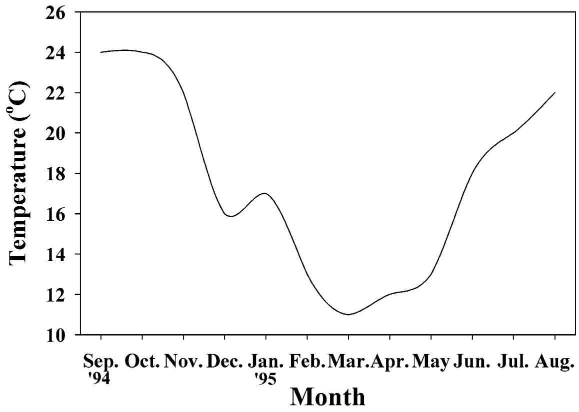

Figure 1. Monthly variations of seawater temperature at Cheongsapo in Korea.

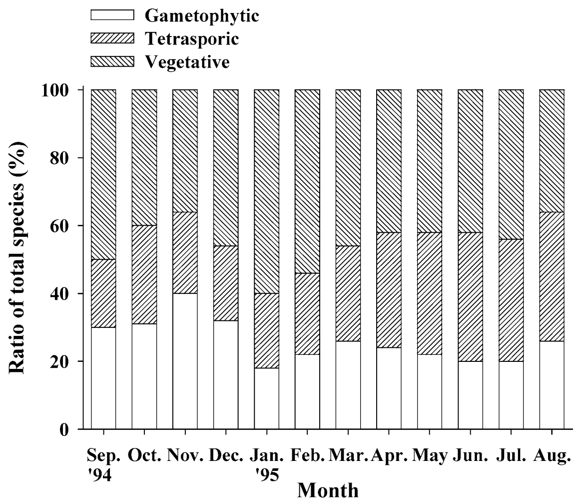

Figure 2. Monthly proportions of reproductive phases of *Chondrus ocellatus* during the sampling period.

The average length per plant was 6.99 ± 3.29 cm (mean ± SD) for gametophytic plants, 7.93 ± 3.61 cm for tetrasporic plants and 5.99 ± 2.89 cm for vegetative plants (Figure 3). Vegetative plants were smaller than reproductive plants. Growth in thallus length of vegetative and reproductive plants was highest in October, May and August whereas it was lowest in February and March (Figure 3). Monthly size distributions of thalli including all reproductive phases varied during the study period (Figure 4). From December to February

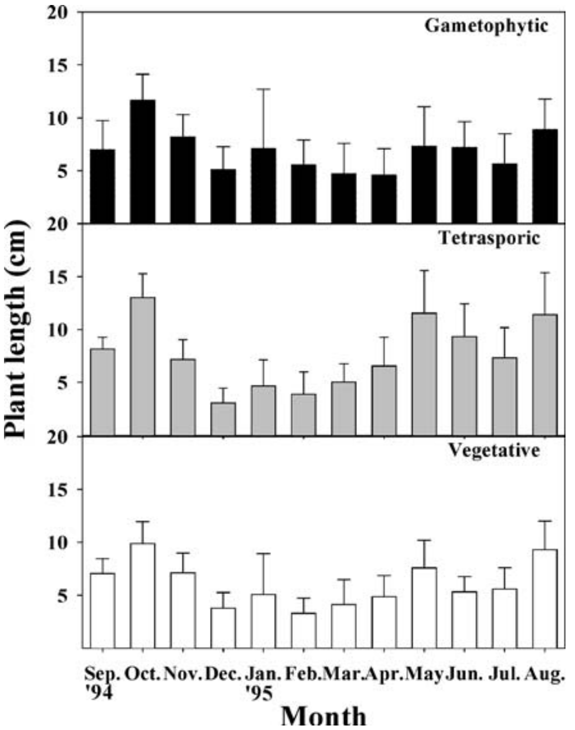

Figure 3. Mean plant length (± SD) for each reproductive phase of *Chondrus ocellatus* during sampling period.

(winter), small plants (below 4 cm) constituted about 60% of the population. Medium-sized plants (4–12 cm) comprised above 50% of the population from March to November except October.

In terms of thallus weight (Figure 5), the average wet weight per plant was 6.92 ± 3.47 g (mean ± SD) for gametophytes, 7.28 ± 4.29 g for tetrasporophytes and 4.22 ± 3.32 g for vegetative plants. Seasonal variations of wet weight of thallus showed a trend towards heavier plants in spring and autumn and lighter plants in winter.

In laboratory culture, a maximum RGR of 2.94% day^{-1} was obtained at 20 °C and 100 μmol photons m^{-2} s^{-1}, whereas the lowest value was recorded at 25 °C and 100 μmol photons m^{-2} s^{-1} (Figure 6). RGR of *Chondrus ocellatus* was the highest in 20 °C and there were significant differences in RGR among the examined temperatures of 15, 20 and 25 °C (ANOVA, $p < 0.05$). A Tukey test revealed the RGR of *C. ocellatus* was significantly different between 20 and 25 °C. With respect to photoperiod, although the highest RGR was apparently at 12:12 h LD, followed by 16:8 h LD and 8:16 h LD, there were no significant differences in RGR among them (ANOVA, $p > 0.05$, Figure 7).

Discussion

Vegetative, gametophytic and tetrasporic plants were found throughout the year. Reproductive plants including both gameto- and tetrasporophytes were most abundant in November and August when the temperature was 20 °C. However, sexual and asexual plants showed different patterns. Gametophytes were most abundant from September to December, when temperature and daylength decrease. In contrast, tetrasporophytes exceeded gametophytes in other months, particularly from April to August, when temperature and daylength increase. This pattern of association of reproductive plants with lower seawater temperatures and solar radiation is also found in *Gracilaria* (Piriz, 1996) and may result from different in physiological responses of gametophyte and tetrasporophyte phases to temperature and irradiance. Hannach and Santelices (1985) reported that gametophytic plants of *Iridaea* had a higher growth rate than tetrasporic plants under the same experimental conditions.

The growth of vegetative and reproductive plants (measured as thallus length) was highest in October, May and August when temperatures were highest at around 22–24 °C. In contrast, thalli were shortest in February and March, when temperature decreased from 15 °C to the lowest recorded value of 11 °C. This seasonal pattern in size distribution may be related not only to seawater temperature but also to reproduction and wave action. Generally, in July and August, several typhoons strike the Korean Peninsula, causing many seaweeds to become detached from the substratum. Also, the fronds of *C. ocellatus* die back after reproduction, as found in *Gracilaria* and *Eucheuma* (Dawes et al., 1974; Destombe et al., 1988) and it affects the size distribution of the species. In the study area, reproductive thalli are mainly seen from spring to autumn. The empty reproductive structures (after releasing spores) probably weaken the fronds, leading to decay of thalli which is accelerated by tyhoons tearing the weak fronds. Therefore it is not easy to determine the relative importance, to size distribution, of typhoons and reproduction in *C. ocellatus*. The rapid increase in the frequency of small plants (below 4 cm) from December to February may reflect the decay of larger plants and recruitment of new individuals after reproduction. High frequency of smaller plants during the period mainly results from dying back caused by reproduction and typhoons rather than new recruitments because we observed many smaller fronds have been torn. In the field population, larger plants become more

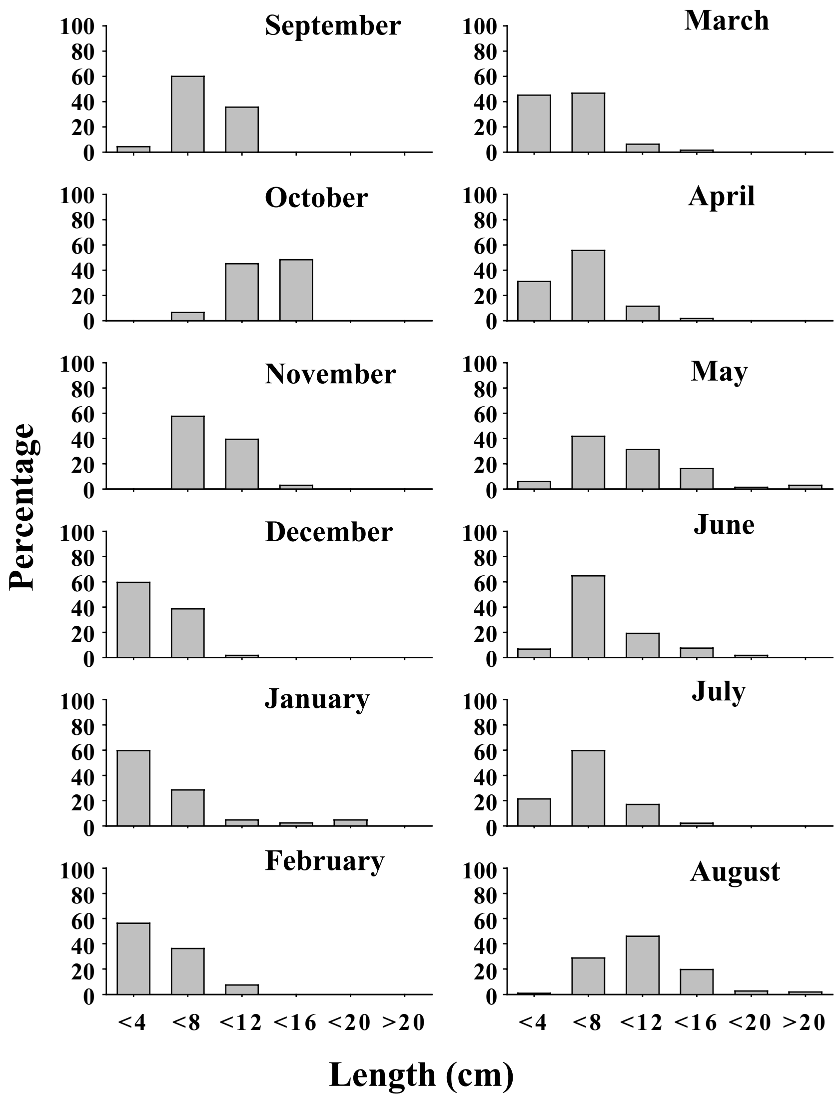

Figure 4. Size frequencies of *Chondrus ocellatus* collected over all the sampling period.

abundant from March to October and they were maximal in October, when seawater temperature is about 24 °C. In culture, however, the RGR of *C. ocellatus* was maximal at 20 °C and lowest at 25 °C. The large size of the plants in October is probably the result of growth in the previous months (June–August), when mean seawater temperature is about 20 °C. A similar pattern is also found in the weight of plants. These results suggest that the growth and reproduction of *C. ocellatus* are related to water temperature.

With respect to photoperiod, the highest RGR was found in 12:12 h LD, followed by 16:8 h LD and 8:16 h LD, indicating that this factor also affects the growth of *C. ocellatus*.

RGR is an important element in the evaluation of potential biomass production. In commercial algae, high RGR is essential for mass production. The RGR of *C. ocellatus* in culture ranged from 1.33 to 2.94% day^{-1}. These values are lower than those reported for *Chondrus crispus* (2–4% day^{-1}: Chopin et al., 1999) and for the other carrageenophytes *Eucheuma* and *Kappaphycus* (2–6% day^{-1} : Braud & Perez, 1979; Ohno et al., 1994). However, the RGR of *C. ocellatus* could be enhanced by culture in better designed growth conditions, with optimal temperature, light, salinity and nutrients. Thus, future studies on the growth of *C. ocellatus* should be carried out to determine these optimal conditions for commercial cultivation.

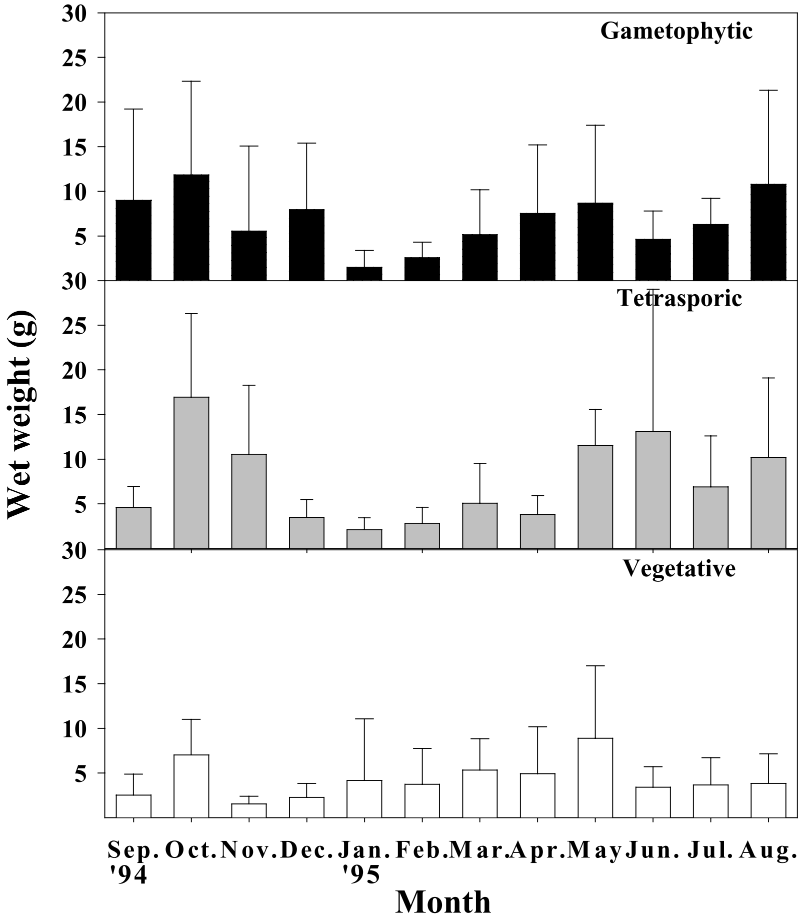

Figure 5. Mean wet weight (± SD) of plants for each reproductive phase of *Chondrus ocellatus* during sampling period.

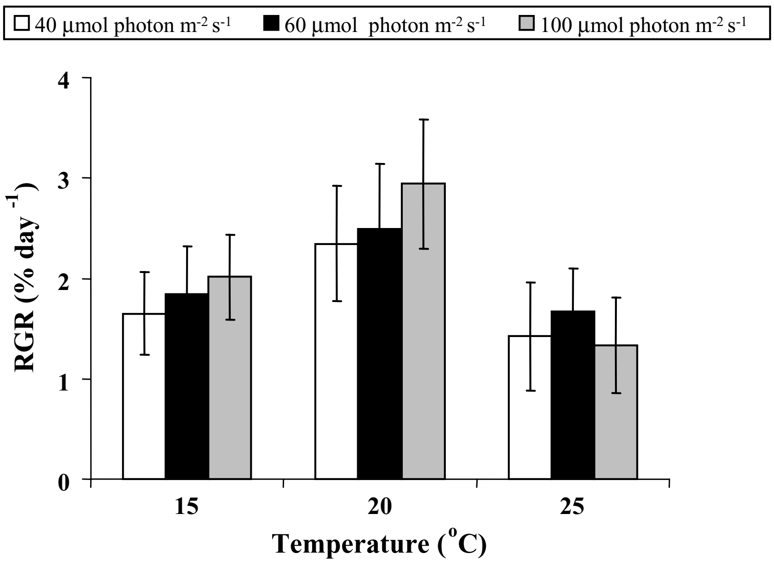

Figure 6. Relative growth rate (± SD) of *Chondrus ocellatus* at different temperatures and light intensities under 12 L:12 D photoperiod regime.

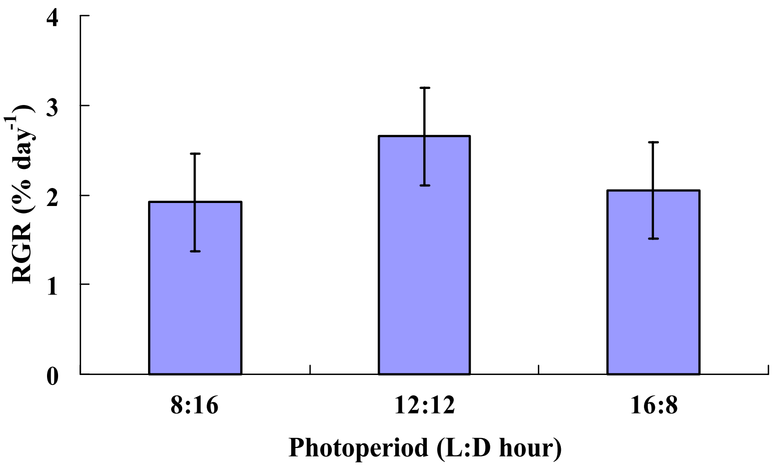

Figure 7. Relative growth rate (± SD) of *Chondrus ocellatus* at different photoperiod regimes under 15 °C and 60 μmol photons m^{-2} s^{-1}.

In conclusion, the seasonal patterns in abundance of vegetative and reproductive plants are associated with the combined factors of photoperiod and temperature. Sexual plants are most abundant near autumn and winter, and tetrasporophytes in spring and summer. Growth is greatest when temperatures are highest (summer and autumn). These results are useful for the timing of harvests of *C. ocellatus* in the field. Furthermore, the results of this study are useful for potential future cultivation of this economically important species.

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