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Growth rates in culture of several species of *Sargassum* from Florida, USA

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Introduction

When suitable substrate is present, benthic species of the brown algal genus *Sargassum* are often predominant components of shallow subtidal communities in tropical and subtropical waters (Tsuda, 1972; Wanders, 1976; Connor & Adey, 1977; Cordero, 1981; Morrissey, 1980). Such is the case in shallow subtidal areas of Florida and Caribbean waters where at least twelve benthic species of *Sargassum* occur (Taylor, 1960). In addition, two pelagic species, *S. fluitans* Børgesen and *S. natans* (Linnaeus) Gaillon, can form large accumulations in the Sargasso Sea, the Gulf Stream, and the Gulf of Mexico, although the average standing crop of these species over these vast areas is quite low (Parr, 1939). Most previous investigators (*e.g.*, Howard & Menzies, 1969; Carpenter & Cox, 1974; Blake & Johnson, 1976; Mann *et al.*, 1980) believe that the productivity of pelagic *Sargassum* is quite low, but recent research (Lapointe, 1986) has demonstrated that the growth rate and productivity of these species can be much higher than previously reported, with rates approximating those of productive benthic macroalgae.

Owing to the potential ability of *Sargassum* to accumulate large quantities of biomass, as well as to its positive buoyancy, *Sargassum* has been proposed as a possible candidate for floating seaweed "energy farms" (Ryther *et al.*, 1980; Hanisak, 1987; Bird *et al.*, 1987). *Sargassum* might also be harvested or cultivated for its alginate.

However, despite the importance of *Sargassum* in subtropical and tropical waters, both in terms of ecological significance and maricultural potential, little is known about what controls the seasonal growth patterns and other aspects of the physiological ecology of this genus. Accordingly, a study was initiated on the biology of the genus *Sargassum*, with emphasis on species found in Florida and adjacent waters. This communication reports on a series of experiments that measured the effects of photon flux density, temperature, and salinity on the growth rates in culture of several species of *Sargassum* common to these waters.

Materials and methods

Thalli of six species (based on Taylor, 1960) were collected from Florida waters (Table 1). Clonal cultures were initiated from freshly collected thalli that had been washed in sterile seawater and examined for visible epiphytes. Small, clean growing tips were isolated into culture dishes containing Provasoli's Enriched Seawater (PES) (Provasoli, 1968), without vitamins added to the media. Stock cultures were maintained in PES, initially in 400-mL culture dishes (*i.e.*, Pyrex® storage dishes) or, as biomass began to accumulate for each clone, in aerated, 3.8-L polycarbonate jars. These stock cultures were maintained under standard conditions of 24°C, 36‰ salinity, 14:10 h L:D cycle, and *ca* 250 $\mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ of cool-white fluorescent light.

Table 1. Species of *Sargassum* and their collection sites for cultures examined in this study. All sites are located in Florida waters.

Species	Collection sites
<i>S. cymosum</i> C. Agardh	Sebastian Reef
<i>S. filipendula</i> C. Agardh	Homosassa Bay
<i>S. fluitans</i> Børgesen	Gulf Stream off Fort Pierce
<i>S. natans</i> (Linnaeus) Gaillon	Gulf Stream off Fort Pierce
<i>S. polyceratium</i> Montagne	Content Keys
<i>S. pteropleuron</i> Grunow	Indian River Lagoon

The day before each experiment, apical tips, 20 mm in length, were cut from the appropriate clones and placed into culture dishes. On the day each experiment began (*i.e.*, day 0), individual apical tips were blotted with a Kimwipe® to remove excess water, quickly weighed to the nearest 0.1 mg on an analytical balance, and then placed into a culture dish containing 200 mL of PES under the appropriate experimental conditions. The medium was changed every seven days, at which times the blotted wet weight was also measured.

Experiments were performed to determine the effects of different temperature-salinity and temperature-photon flux density (PFD) combinations on growth. Temperature-salinity experiments were conducted at $110 \mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, 14:10 h L:D, over the temperature range of 12° to 30°C (in 6°C increments) and a salinity range of 6 to 42‰ (in 6‰ increments). Salinities in these experiments were obtained by either diluting (6 to 30‰) natural seawater (salinity = 35–36‰) with deionized water or adding (42‰) proper amounts of synthetic seawater salts (Instant Ocean; Aquarium Systems, Inc.). The interaction of PFD (up to 13 levels, ranging from $8-576 \mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) and temperature (18 and 24°C) was examined at 14:10 h L:D and 36‰. Experiments were run in triplicate under each set of conditions, and all experiments were repeated.

After 21 days, the experiments were terminated and dry weights determined (≥ 48 h at 80°C). Initial dry weights were estimated by measuring the percent dry weight of additional apical tips ($n=3$) and multiplying this value by the initial blotted wet weight. From the initial (day 0) and final (day 21) measurements of dry weight, specific growth rates were calculated from the equation:

$$k = \frac{\log_2(W_t/W_i)}{t}$$

where k = the specific growth rate expressed as doublings per day, W_i = the initial weight of the thallus, and W_t = the weight of the plant after t number of days.

Results

Several trends were observed in the growth response of these species of *Sargassum* to changes in temperature, salinity, and photon flux density. Growth rate was maximal for most species at 24–30°C, with sharp decreases in growth occurring below that temperature range (*e.g.*, Fig. 1). Two species (*S. natans* and *S. pteropleuron*) had a broader optimal temperature range of 18–30°C (Fig. 2). All benthic species had a measurable growth rate at the lowest temperature examined (12°C); however, growth of the two pelagic species (*S. fluitans* and *S. natans*) was not detectable at 12°C. Additional experiments (data not shown) indicated that the growth rate of all species, benthic and pelagic, decreased rapidly above 30°C.

Benthic species grew over a much broader salinity range than did pelagic ones (*e.g.*, Fig. 3). The optimal salinity range for most benthic species was 24–42‰, with most species capable of some growth at 12‰; *S. filipendula* was able to grow at the lowest salinity tested (6‰). In contrast to the benthic species, the pelagic species were stenohaline, with an optimal salinity range for growth of 36–42‰. A reduction in salinity to 30‰ caused a reduction in the growth rates of both *S. fluitans* and *S. natans* by almost half. No growth of these pelagic species occurred below 18‰. Changes in salinity did not alter the previously stated optimal temperature ranges.

Under optimal conditions, the growth rates of the benthic species were typically saturated at a photon flux density of *ca* $150 \mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (*e.g.*, Fig. 4). Compensation levels were low (*ca* $10-20 \mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) for the benthic species. Under the same conditions, the growth rates of the pelagic species were typically saturated at *ca*

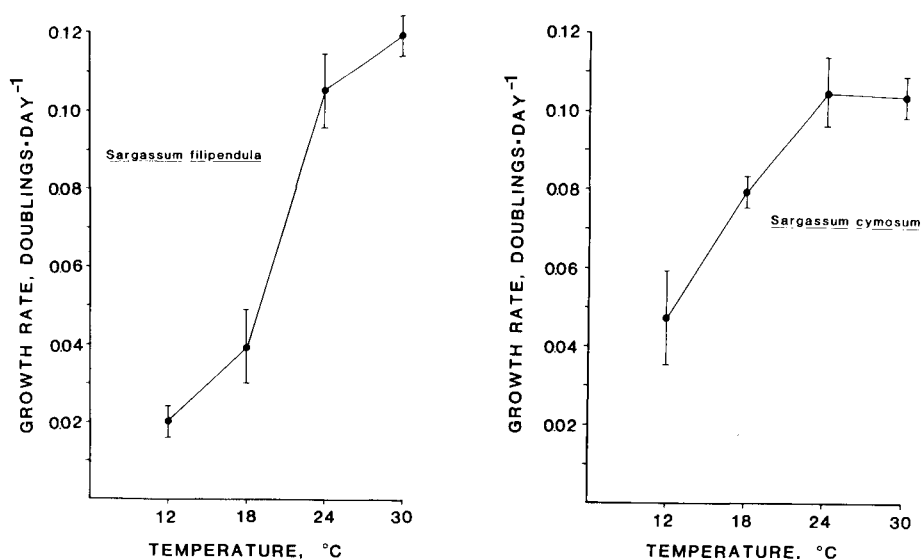


Fig. 1. Specific growth rate (doublings · day⁻¹) of *Sargassum filipendula* and *S. cymosum*, both benthic species, as a function of temperature (bars around the data points indicate standard errors, $n = 6$).

200–300 $\mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ (e.g., Fig. 5). Compensation levels of the pelagic species were also higher (ca 25–50 $\mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$) than those of the benthic species. For most benthic and pelagic species, light saturation and light compensation occurred at lower intensities when the temperature decreased from 24°C to 18°C (Figs 4, 5).

An examination of maximal growth rates measured during all the experiments conducted to date

(Table 2) indicated that both benthic and pelagic species of *Sargassum* had high growth rates under favorable conditions. Of the benthic species, *S. filipendula* and *S. pteropleuron* had the highest growth rates. Of the pelagic species, *S. fluitans* had a higher growth rate than *S. natans*.

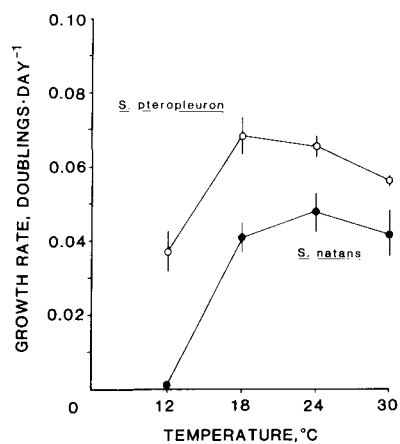


Fig. 2. Specific growth rate (doublings · day⁻¹) of *Sargassum natans*, a pelagic species, and *S. pteropleuron*, a benthic species, as a function of temperature (bars around data points indicate standard errors, $n = 6$).

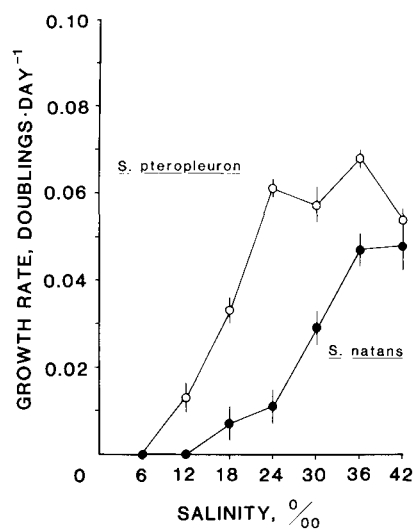


Fig. 3. Specific growth rate (doublings · day⁻¹) of *Sargassum natans*, a pelagic species, and *S. pteropleuron*, a benthic species, as a function of salinity (bars around data points indicate standard errors, $n = 6$).

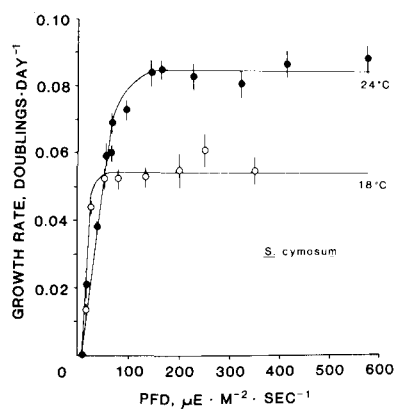


Fig. 4. Specific growth rate (doublings · day⁻¹) of *Sargassum cymosum*, a benthic species, as a function of photon flux density (PFD) at 18°C and 24°C (bars around data points indicate standard errors, $n = 6$).

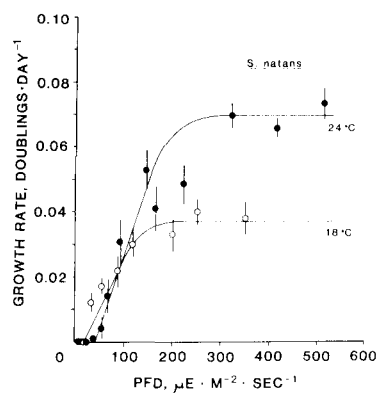


Fig. 5. Specific growth rate (doublings · day⁻¹) of *Sargassum natans*, a pelagic species, as a function of photon flux density (PFD) at 18°C and 24°C (bars around data points indicate standard errors, $n = 6$).

Table 2. Maximal growth rates in culture of six species of *Sargassum* measured during this study. Data are presented as $\bar{x} \pm S.E.$

Species	Maximal growth rate (doublings · day ⁻¹)
<i>S. cymosum</i>	0.0944 ± 0.0105
<i>S. filipendula</i>	0.1071 ± 0.0030
<i>S. fluitans</i>	0.1089 ± 0.0027
<i>S. natans</i>	0.0727 ± 0.0049
<i>S. polyceratum</i>	0.0787 ± 0.0153
<i>S. pteropleuron</i>	0.1117 ± 0.0080

Discussion

The growth rates of the pelagic species of *Sargassum* measured in this study are similar to those recently obtained during an *in situ* nutrient enrichment study by Lapointe (1986). Both studies indicate that these pelagic species are capable of rapid growth, much faster than generally believed (e.g., Michanek 1975; Mann *et al.*, 1980).

One long-standing question in the phycological literature concerns the origin of the pelagic species of *Sargassum* (Krümmel, 1981; Winge, 1923; Parr, 1939). Are populations of the species continually being renewed from some unknown, benthic

source? Or are the pelagic species distinctly separate from benthic ones and capable of maintaining themselves completely by vegetative reproduction? While this study did not address this question directly, several interesting contrasts between the benthic and pelagic species were observed that suggest that there are significant physiological differences between the benthic and pelagic species.

First, the pelagic species of *Sargassum* are more stenohaline than the benthic ones. This presumably indicates a lack of adaptation of the pelagic species for growth in areas of reduced salinity commonly found in estuarine and some coastal areas. Benthic species, on the other hand, are capable of surviving and growing over the wide range of salinity found in such areas.

Second, the pelagic species of *Sargassum* have a higher light requirement than the benthic species. Presumably this indicates the adaptation of the pelagic species to high-light ("sun") conditions and the benthic species to low-light ("shade") conditions found in their respective habitats.

Because pelagic species *Sargassum* are naturally buoyant due to their air bladders, these algae, from a practical standpoint, may be the best suited of all seaweeds for open-water cultivation in oceanic or coastal waters. Benthic species of *Sargassum* may be capable of being cultivated in a floating mode or alternatively may be cultivated in shallow waters.

Preliminary economic analyses of such farms point to apparently favorable prospects (Bird, 1987).

The results of this study, combined with other *in situ* studies, will help to elucidate the interaction of the growth of *Sargassum* and its physical environment and to evaluate the potential of *Sargassum* for cultivation. The temperature experiments conducted in this study have demonstrated that any of the species of *Sargassum* can survive and grow under the temperature conditions normally found in the coastal or marine waters of Florida and adjacent waters in the Bahamas and Caribbean. Furthermore, in most prospective sites for possible large-scale cultivation (e.g., the Florida Keys, the Gulf of Mexico), temperature conditions will be in the optimal range for most, or all, of the year. The salinity experiments indicate that cultivation of the two pelagic species should be considered only under oceanic conditions.

As studies on the phenology of growth and reproduction continue in Florida waters (Hanisak, unpubl.), the data obtained on the influence of major environmental factors on growth will be important in explaining the observed patterns. Additional research will be required on environmental triggers of sexual reproduction, nutrient requirements and dynamics, and other aspects of the physiological ecology of this genus.

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