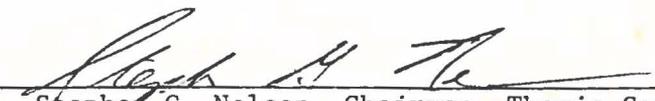


AN ABSTRACT OF THE THESIS OF Spensin James for the Master of Science in Biology presented August 3, 1982.

Title: Photosynthesis and respiration of two species of red algae, Gracilaria arcuata and Gracilaria edulis, from Guam.

Approved:


Stephen G. Nelson, Chairman, Thesis Committee

Rates of photosynthesis and respiration were determined for G. arcuata and G. edulis at temperatures of 0°, 20°, 30°, and 40°C and salinities of 10, 20, and 30‰. The photosynthetic rates ranged from 1.5 to 45.5 μl oxygen/g dry wt/min. The photosynthetic rates were not significantly affected by salinity but increased with an increase in temperature. Both species showed maximum rates of photosynthesis at 40°C, the highest temperature tested. Rates of respiration were unaffected by salinity. Respiration rates ranged from 1.3 to 25.6 μl oxygen/g dry wt/min.

The photosynthetic rates of G. arcuata and G. edulis at 28.5°C and 33°C under a range of irradiances showed an increase in net oxygen production by each species above saturating irradiances as the temperature increased. The saturation points occurred at 230 $\mu\text{E}/\text{m}^2/\text{sec}$ for both species.

The results indicate that these species could be cultivated in environments of high temperature and over a wide salinity range.

PHOTOSYNTHESIS AND RESPIRATION OF TWO SPECIES OF RED ALGAE,
GRACILARIA ARCUATA AND GRACILARIA EDULIS, FROM GUAM

by
SPENSIN JAMES

A thesis submitted in partial fulfillment of the
requirements for the degree of

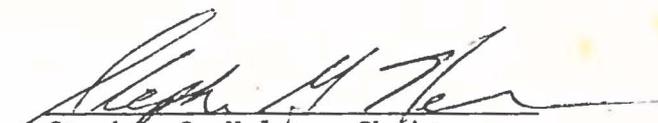
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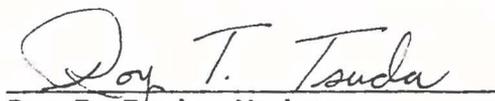
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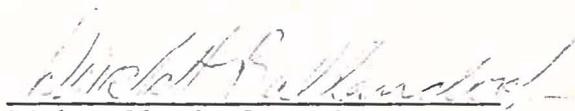
TO THE GRADUATE SCHOOL AND RESEARCH

The members of the Committee approve the thesis of Spensin James presented August 3, 1982.


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INTRODUCTION

For centuries, marine macroalgae, popularly known as seaweeds, have been an integral part of the diet in the Orient. It was not until the early twentieth century that these seaweeds were considered to have economic and dietary value in the western world (DeBoer and Ryther, 1977). Some seaweeds have recently found use in the United States, Japan, and other parts of the world primarily as sources of phycocolloids (alginates, agar, and carrageenan). The cell wall polysaccharides of some seaweeds include agar or carrageenan, phycocolloids which have been widely used in the production of processed food, pharmaceuticals, textiles and cosmetics, as suspending, thickening, stabilizing, and emulsifying agents (Chapman, 1970).

As a result of the limited seaweed resources and the increasing demand for phycocolloids, world-wide attempts have been undertaken to screen various species of seaweeds to determine their potential for use by the phycocolloid industry. Examples of recent studies aimed at furthering the expansion of this industry include the exploitation of Eucheuma species in the Philippines, outplanting and mariculture of Eucheuma species and Gracilaria species in Micronesia (Doty, 1980; Nelson et al., 1980), extensive cultivation of Gracilaria species in Taiwan (Chen, 1976), and the cultivation of Gracilaria species in Japan (Suto, 1974).

There is little information available on the environmental physiology of the phycocolloid-producing algae; however, such information is

essential to an understanding of the mechanisms underlying seaweed production. Studies that have been done on the subject include the works of Ogata and Matsui (1965), Ogata and Takada (1968), Mathieson and Dawes (1974), Dawes et al. (1976 and 1978), Ramus et al. (1976), and Glenn and Doty (1981). Most of these studies have been concerned with either temperate or subtropical species. Other than the work of Glenn and Doty (1981), no studies have been done on environmental effects on photosynthetic and respiration rates of tropical phycocolloid-producing algae.

The objective of this paper is to determine the effects of salinity and temperature on the rates of photosynthesis and respiration of two tropical species of agarophytes of the genus Gracilaria (Rhodophyta) found on Guam. This information will be useful in determining the optimum environments of these species for the development of mariculture and outplanting systems in Micronesia.

MATERIALS AND METHODS

Gracilaria arcuata Zanard. and Gracilaria edulis (Gmelin) Silva were collected from Pago Bay and Cetti Bay and brought to the University of Guam Marine Laboratory. They were grown in an environmental chamber for two to three days at 29°C in filtered (0.45 μm) seawater at a photoperiod of 12 hours of dark and 12 hours of light (262 $\mu\text{E}/\text{m}^2/\text{sec}$).

Rates of photosynthesis and respiration were measured manometrically with a Gilson respirometer (GPR-20) in accordance with the procedures used by Dawes et al. (1976). Apical portions of the Gracilaria, about 250–350 mg wet weight, were used in each flask. The side arms of the flasks were provided with 0.5 to 0.6 ml of KOH along with a fluted piece of filter paper to maintain a 1% carbon dioxide atmosphere in the flasks. The flasks were allowed to equilibrate 15 to 20 minutes before the start of each measurement.

Each respirometer run was conducted in the afternoon for 65 to 80 minutes, and readings were taken at 10-minute intervals. Salinities of 10‰, 20‰, and 30‰, and temperatures of 10°, 20°, 30°, and 40°C were used in all possible combinations. All photosynthetic runs were made at a constant photon flux density of 265 $\mu\text{E}/\text{m}^2/\text{sec}$ similar to that used by other investigators (Mathieson and Dawes, 1974; Glenn and Doty, 1981). Four replicates were used for each respirometer run, after which the seaweed pieces were oven dried overnight at 50°C and weighed to the nearest 0.01 mg on a Sartorius electronic balance. The rates of

apparent photosynthesis and respiration were then calculated in terms of $\mu\text{l O}_2/\text{g dry wt}/\text{min}$ in accordance with Umbriet et al. (1972).

An oxygen probe was used to determine the rates of photosynthesis of G. arcuata and G. edulis thalli in relation to photon flux density (PFD) at temperatures of 28.5° and 33.0°C. The Gracilaria thalli were placed in a sealed, thermostated oxygen electrode chamber that was constantly stirred. A constant temperature in the electrode chamber was maintained by pumping water into the chamber surrounding the electrode chamber from a 50-liter aquarium equipped with a temperature controller and heater. The light was alternately turned on and off and the photon flux density was varied by the use of a potentiometer attached to six strips of 40-watt fluorescent flood lights. Photon flux density was measured in $\mu\text{E}/\text{m}^2/\text{sec}$ with a quantum photometer (Licor, 185). Changes in dissolved oxygen in the chamber were measured with a radiometer electrode connected to a Strathkelvin Oxygen Meter (model 381) and recorded on a Houston Instrument strip-chart recorder (model B-500).

RESULTS

The influence of various combinations of temperature and salinity of seawater on the apparent photosynthetic activities of G. arcuata and G. edulis is illustrated in Figure 1. Both species showed maximum net oxygen production at 40°C. At this temperature the highest photosynthetic rates were found at 10‰ for G. edulis and 30‰ for G. arcuata. A three-way anova (Table 1) showed that there was a significant difference between the photosynthetic rates of G. edulis and G. arcuata thalli ($p < 0.05$) and showed that temperature had a significant effect on the rate of photosynthesis ($F = 88.06$, $p < 0.05$). However, the effect of salinity was not significant ($F = 0.30$, $p > 0.05$), and there were no significant interaction effects between temperature and salinity.

Figure 2 illustrates the respiration rates for G. arcuata and G. edulis and indicates a similar increase in respiration rates for both species up to 40°C. A three-way anova (Table 1) revealed that there was no significant difference between the respiration rates of the two Gracilaria species. The only factor that had a significant effect ($F = 124.37$, $p < 0.05$) on the respiration rates was temperature. Salinity had no effect ($F = 0.69$, $p > 0.05$), and there was no significant interaction effect.

Figure 3 illustrates the rates of photosynthesis of G. arcuata and G. edulis thalli at 28.5°C and 33.0°C under a range of irradiances. The net oxygen production at saturation by each species increased with temperature as did the initial slopes, as shown in Table 2. The

Table 1. Anova table for photosynthesis and respiration of G. arcuata and G. edulis.

Source of variations	df	MS	FS
Photosynthesis			
Species	1	13.96	5.45*
Salinity	2	0.78	0.30ns
Temperature	3	226.82	88.60**
Species x Salinity	2	4.36	1.70ns
Species x Temperature	3	11.67	4.56*
Salinity x Temperature	6	2.39	0.93ns
Species x Salinity x Temperature	6	2.56	
Respiration			
Species	1	0.61	0.90ns
Salinity	2	0.47	0.69ns
Temperature	3	84.57	124.37**
Species x Salinity	2	0.60	0.88ns
Species x Temperature	3	0.83	1.22ns
Salinity x Temperature	6	0.76	1.12ns
Species x Salinity x Temperature	6	0.68	1.12ns

* significant ($p < .05$)
 ** very significant ($p < .01$)
 ns not significant

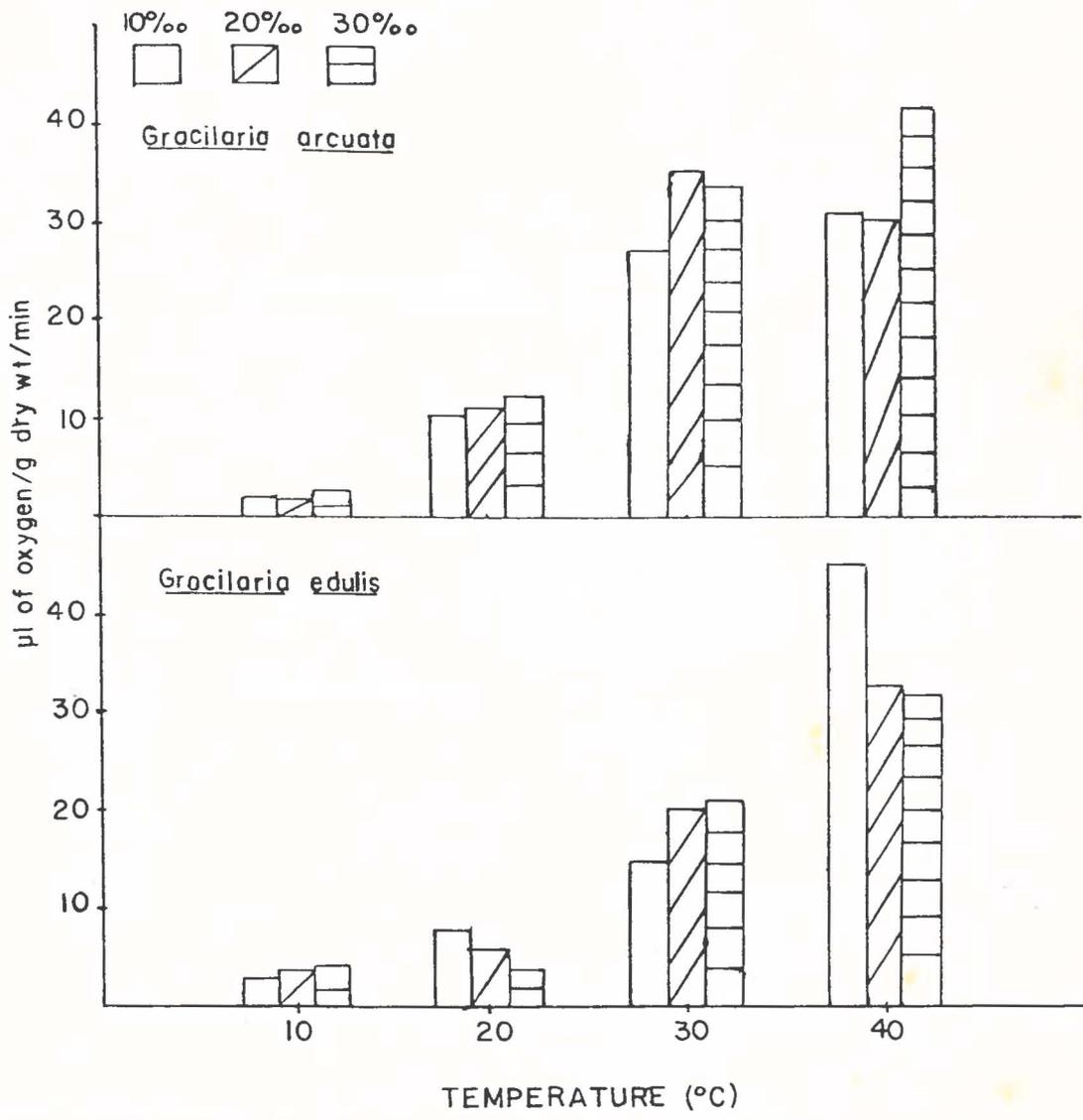


Figure 1. Apparent photosynthesis of *Gracilaria arcuata* and *Gracilaria edulis* at 10°, 20°, 30°, and 40°C after 3 days of immersion in various salinities and 265 $\mu\text{E}/\text{m}^2/\text{sec}$.

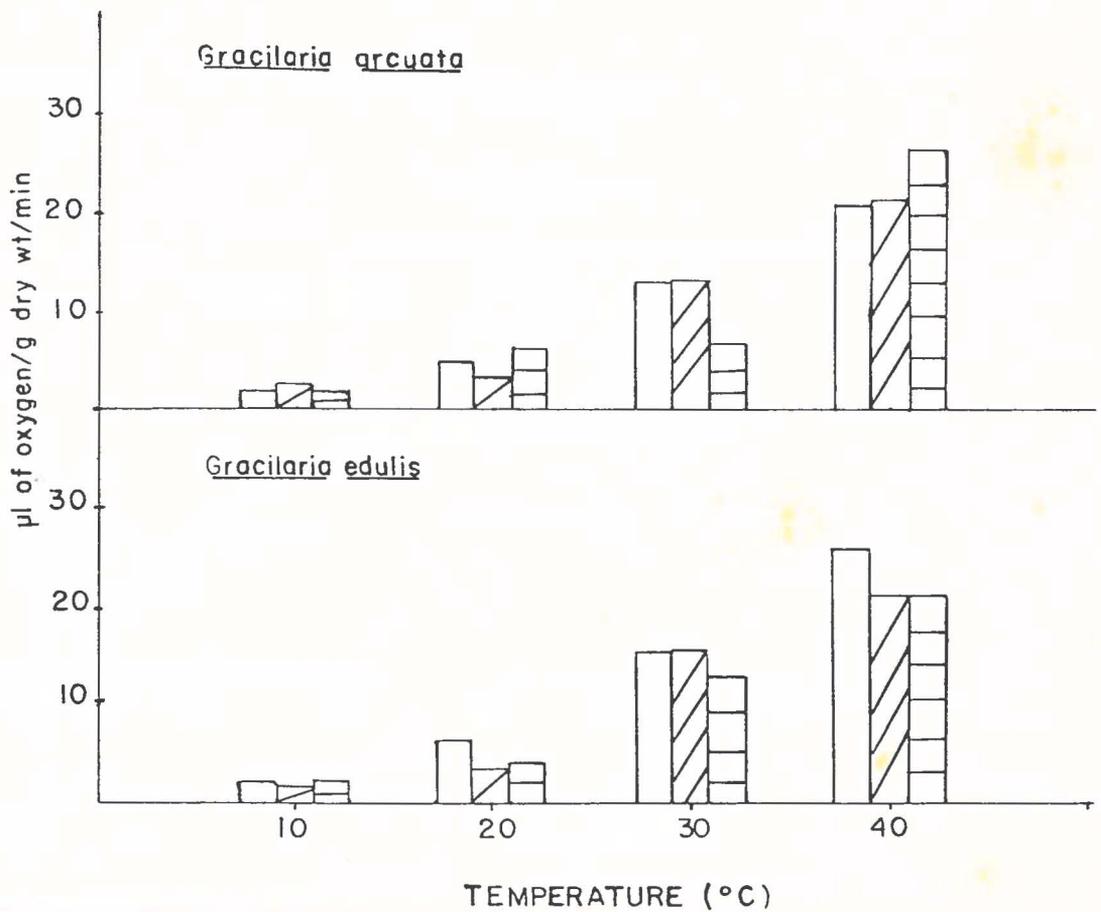


Figure 2. Respiration of Gracilaria arcuata and Gracilaria edulis at 10°, 20°, 30°, and 40°C after 3 days of immersion in various salinities.

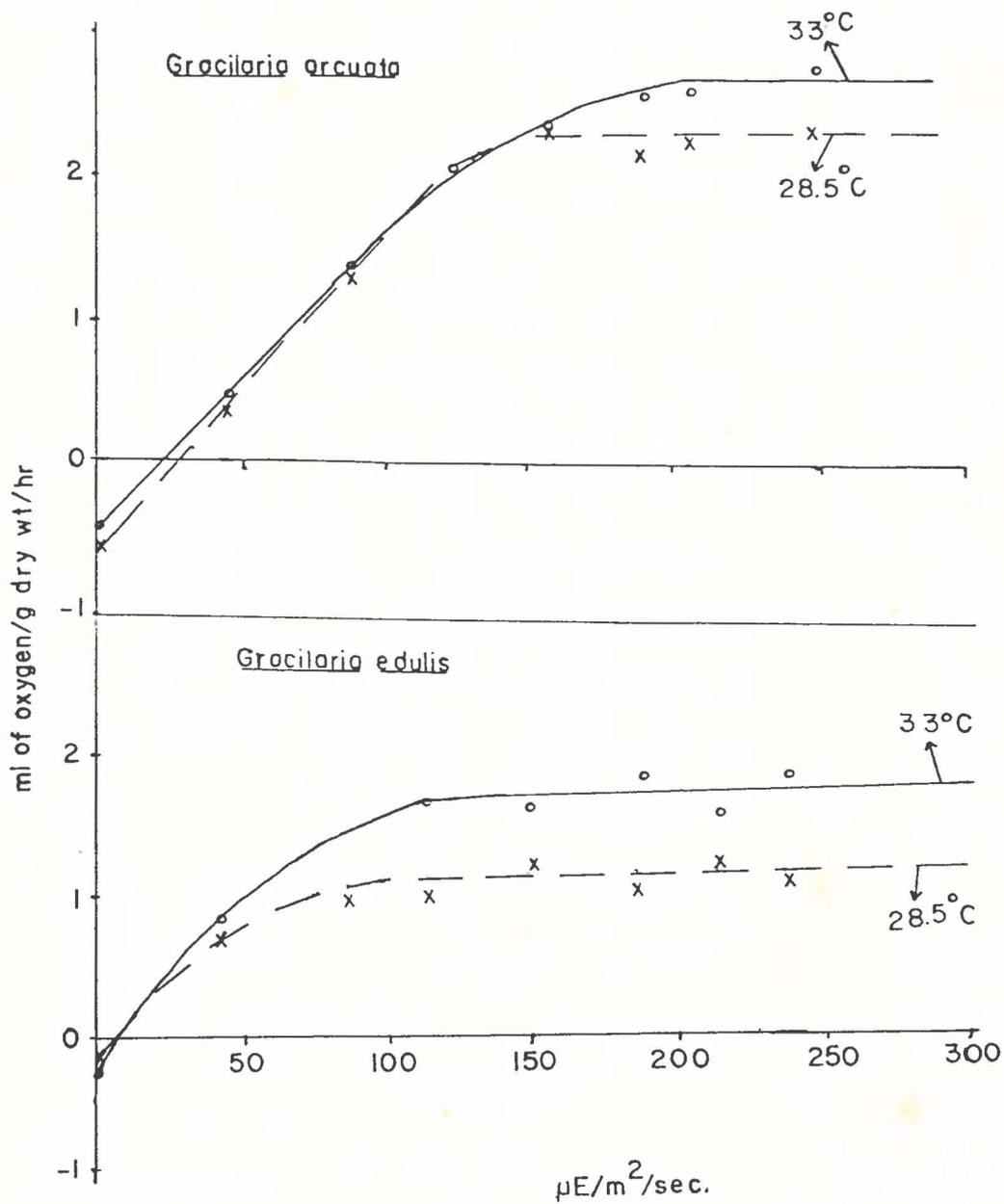


Figure 3. Photosynthesis of Gracilaria arcuata and Gracilaria edulis in relation to temperature and photon flux density.

compensation point decreased slightly with an increase in temperature,
as shown in Table 2.

Table 2. Maximum photosynthesis, saturation points, initial slopes, compensation points, and Michealis-Menton constants, obtained from Figure 3.

Species	Temp.	P _{max}	I _k	Initial Slope	K	I _c	r
<u>Gracilaria edulis</u>	33.0°C	1.75	80	0.02	-71	5	0.83
	28.5°C	1.30	50	0.01	-90	10	0.75
<u>Gracilaria arcuata</u>	33.0°C	2.80	150	0.02	- 2.2	25	0.91
	28.5°C	2.20	130	0.005	- 1.0	30	0.84

DISCUSSION

The present study on the combined effects of salinity and temperature on the net oxygen production and respiration of Gracilaria arcuata and Gracilaria edulis revealed that the rates of apparent photosynthesis of the thalli of two species were significantly different, but that there was no significant difference in the rates of respiration. This is not surprising since the photosynthetic rate can be influenced by factors such as pigment content and the degree of self shading.

Respiration, on the other hand, is less subject to such influences.

Also, Littler and Murray (1974) and Ramus (1976) indicated that thallus form influences the photosynthetic responses of marine algae.

Both photosynthesis and respiration, as expected, increased with temperature. The observed higher respiration at higher temperatures could also indicate that these Gracilaria species prefer higher temperatures for growth and metabolism as suggested by the work of Durako and Dawes (1980). Similarities found between the respiration of these two Gracilaria species may result from either quantitative or qualitative (isoenzymes) similarities in the respiratory enzymes of the two species (Mathieson and Dawes, 1974). Dawes et al. (1978) reported that Gracilaria species from a mangrove community exhibited greater photosynthetic responses under varying temperatures than with algae from a salt marsh community. Simonetti et al. (1970) showed in their studies that the Gracilaria species they worked with had highest photosynthetic rates when the temperature was high (around 30°C) during the summer.

Mathieson and Noral (1975) indicated through their study on the photosynthesis of Chondrus crispus that summer plants showed a greater tolerance to high temperature and that they had a higher temperature optimum than winter plants. Other studies by Mathieson and Burns (1971) showed that photosynthesis and respiration of Chondrus crispus collected during the summer exhibited a higher rate of net photosynthesis and respiration over a wide range of temperatures.

Salinity was found to have no significant effect on the photosynthetic activities of the two species used in this study. Other studies, however, showed that even the type of water used in the dilution of natural seawater may influence the photosynthetic rates of marine algae. Ogata and Matsui (1965) found a reduction in algal photosynthetic rates when saltwater was diluted with distilled water. Ogata and Takada (1968) reported from their studies on the respiration of Gracilaria verrucosa in Japan that respiration rates decreased in both very low and very high salinities. In contrast, Nath (1967) reported the rates of respiration of brown algae and green algae were always proportional to the degree of oxygen saturation but were not affected by salinity. It is tempting to consider G. arcuata and G. edulis as genetically adapted to an environment of fluctuating salinity; however, in view of the varied responses of photosynthetic rates of other species of algae, this conclusion would be premature.

In the second series of experiments on photosynthesis of G. arcuata and G. edulis under various irradiances and temperatures of 28.5°C and 33.0°C, photosynthesis, as anticipated, was more efficient at higher temperatures and saturating irradiances. Mathieson and Noral (1975) concluded from their investigation on the photosynthesis of

Chondrus crispus that the higher the temperature of the environment, the higher the optimum temperature for photosynthesis. This is consistent with the results of my study which showed that the optimum temperature for photosynthesis of these tropical species was higher than that reported for subtropical species by Mathieson and Dawes (1974). Differences in thalli pigment content may also explain the differences in photosynthesis between species shown in Figure 3. Zavodnik (1973), for example, has shown that highest levels of photosynthesis were found when pigment levels were lowest.

The rates of photosynthesis observed for the tropical species of Gracilaria from Guam were up to three hundred times higher than those reported for a Caribbean Eucheuma species (Mathieson and Dawes, 1974), but they were within the ranges that have been reported for other red algae. For instance, Glenn and Doty (1981) reported that the photosynthetic rates for the central Pacific species of Eucheuma ranged from 2031-2685 $\mu\text{l oxygen/g dry wt/hr}$ at 24°C in filtered seawater. In comparison, Mathieson and Dawes (1974) reported photosynthetic rates of only 5-10 $\mu\text{l oxygen/g dry wt/hr}$ at temperatures of 20°C and 28°C in salinities of 30‰ and 40‰ for the subtropical species of Eucheuma.

Photosynthesis of the Gracilaria species used in this investigation was saturated at irradiances of $230 \mu\text{E/m}^2/\text{sec}$. In contrast, Glenn and Doty (1981) reported light saturation at about $320 \mu\text{E/m}^2/\text{sec}$, and Mathieson and Dawes (1974) reported light saturation at about $260 \mu\text{E/m}^2/\text{sec}$. The discrepancies among the saturation points may result in part from the degree of self shading of the plant in the experimental vessels.

In conclusion, the Micronesian species of Gracilaria would apparently do well in high-temperature, brackish water or marine culture systems. Production in these systems would be limited by irradiances below approximately $200 \mu\text{E}/\text{m}^2/\text{sec}$.

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