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Biomass production of two *Sargassum* species at Cape Rachado, Malaysia

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Abstract

Seasonality in biomass production of *Sargassum baccularia* (Mertens) C. Agardh and *Sargassum binderi* Sonder ex J. G. Agardh was analysed based on quarterly destructive sampling using a line transect-quadrat method from January 1995 to April 1996. Biomass for both *Sargassum* species showed an unimodal pattern. *S. baccularia* attained high biomass during January 1995 (520.23 g wet weight m^{-2}, 47.88 g dry weight m^{-2}, 13.35 g ash-free dry weight m^{-2}) and July 1995 (501.98 g wet weight m^{-2}, 64.92 g dry weight m^{-2}, 14.00 g ash-free dry weight m^{-2}). *S. binderi* attained the highest biomass in April 1996 (656.13 g wet weight m^{-2}, 80.81 g dry weight m^{-2}, 15.25 g ash-free dry weight m^{-2}) with another high value recorded in July 1995 (429.28 g wet weight m^{-2}, 54.30 g dry weight m^{-2}, 11.20 g ash-free dry weight m^{-2}). Both *Sargassum* species recorded the lowest biomass in January 1996 (*S. baccularia*: 76.14 g wet weight m^{-2}, 9.97 g dry weight m^{-2}, 1.97 g ash-free dry weight m^{-2}; *S. binderi*: 68.21 g wet weight m^{-2}, 8.36 g dry weight m^{-2}, 1.68 g ash-free dry weight m^{-2}). Biomass for both *Sargassum* species was strongly correlated to the thallus length. The population of both *Sargassum* species consisted mainly of young plants with 96% of the *S. baccularia* population and 89% of the *S. binderi* population being shorter than 199 mm. Both *Sargassum* populations recorded low percentage of fertility. The most important factor that controlled the biomass production and reproduction for both *Sargassum* species was rainfall.

Introduction

Malaysia has a high diversity of marine algae, with 261 taxa recorded by Phang (1998). However, only a few studies on the distribution and ecology of marine algae have been reported in Peninsular Malaysia (Sivalingam, 1977, 1978, Arumugam, 1981; Crane, 1981; Phang, 1984, 1986, 1988, 1995) and Sabah (Khew, 1978). *Sargassum* is common in Malaysian waters and only the subgenus *Sargassum* is found in Malaysia. There are a total of 21 species of *Sargassum* recorded in Malaysia (Phang, 1998).

Information on the ecological and phenological aspects of *Sargassum* species in Malaysia is scarce as compared to other neighbouring countries where this genus is gaining more attention because of its economic value. The aim of this research is to establish some baseline data on the *Sargassum* species of Malaysia for its conservation and management for commercial utilisation. This is achieved through:

1. observation of seasonal variation in the standing crop of two *Sargassum* species; that is *Sargassum baccularia* (Mertens) C. Agardh and *Sargassum binderi* Sonder ex J. G. Agardh,
2. determination of the fertility periods and relating them to the mean thallus length and biomass of the species, and
3. correlation of the seasonal variation of biomass with environmental parameters.

In terms of the relationship between phenology and commercial utilisation, observations such as the time of appearance of the reproductive organs, seasonal variation in growth, biomass and development of plants, are necessary for identifying optimal harvest periods and this, in turn, ensures sustainable utilisation of a species.

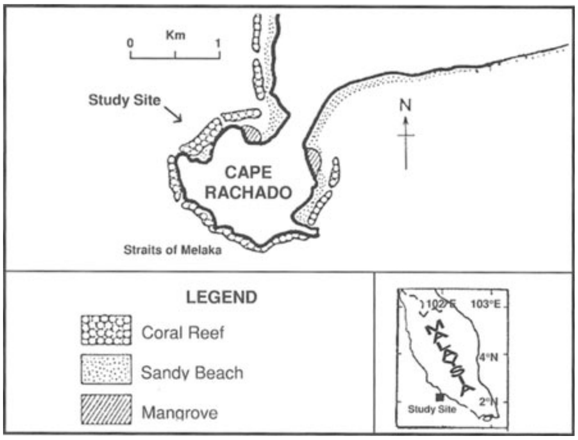

Figure 1. Map showing the location of the study site.

Materials and methods

Study site

Cape Rachado is a fringing coral reef located at Port Dickson, Negeri Sembilan, West Coast of Peninsular Malaysia (Fig. 1). The reef flats extend out to sea for about 110 m and gently slope towards the reef edge to a depth of about 8 m (Goh & Sasekumar, 1980). The reef flats are dominated by *Sargassum*, *Turbinaria* and *Padina* species. Cape Rachado is a famous tourist destination. The study site chosen is a bay surrounded by rocky shore that is less disturbed by tourists as compared with adjacent bays.

The reef flats are completely exposed when the tide level is 0.3 m or less above chart datum (CD). It is completely exposed for more than three hours when the tide level is 0.1 m or less above CD. The lowest tide level (0.1 m or less above CD) during this study period was from February to May 1995 and January to May 1996. The reef flats were exposed 145 times (daytime low tides of 0.3 m or less above CD), for about 1–3 h during the monitoring period (January 1995 to April 1996). Calculations were based on the Tide Tables Malaysia (1995, 1996) for Port Dickson, Negeri Sembilan Darul Khusus (Latitude 2° 31′ N, Longitude 101° 47′ E).

Sampling methods

Destructive sampling for *S. baccularia* and *S. binderi* was conducted quarterly from January 1995 to April 1996. The plants were collected from 0.25 m × 0.25 m quadrats along six line transects every three months during the lowest daytime spring tide. These line transects were laid perpendicular to the shoreline, each 100 m apart. Ten quadrat samples were placed at ten meter intervals along each line transect. Quadrats without both or either one of the *Sargassum* species were also recorded in order to provide information on the spatial distribution pattern of the species.

Twenty-two to 58 quadrat samples were processed each time to determine the seasonal variation in the biomass of both *Sargassum* species. Only *S. baccularia* and *S. binderi* plants within each quadrat were collected and placed in individually labelled plastic bags. The samples were stored in the ice-chest when brought back from the sampling site to the laboratory and were kept in the freezer before processing. All plants were defrosted and rinsed in fresh water to remove sand, silt, epiphytes and other debris before weighing.

Wet weight (WW), dry weight (DW) and ash-free dry weight (AFDW) of the samples were obtained after washing and cleaning. Wet weight of the samples was measured using a top pan balance (Ohaus portable advanced balance) to one decimal point after blotting the samples dry with paper towel. Wet weight values in terms of g m^{-2} were then calculated by multiplying the results obtained by 16, since each quadrat covered an area of 0.0625 m^2. Dry weight of the samples was obtained by drying the samples in the oven at 105 °C for 48 h. The samples were then weighed using the analytical balance (Mettler AJ100) to two decimal points. The values were converted to gram dry weight per m^2 (g DW m^{-2}). The dried samples were placed in dry and clean ceramic crucibles and combusted in the muffle furnace at 550 °C for 6 h. After combustion, the samples were weighed using the analytical balance (Mettler AJ100) to two decimal points and subtracted from the initial dry weight to give the ash-free dry weight. Subsampling was performed whenever combustion of an entire sample was impossible. These values were converted to gram ash-free dry weight per m^2 (g AFDW m^{-2}).

Thallus length of all the plants was measured before obtaining the wet weight. Thallus length was measured as the distance from the end of the holdfast to the apex of the longest branch. The measured length of all plants was averaged to give the mean plant length. Reproductive state was recorded by the presence of receptacles on plants in each quadrat for each sampling period. The receptacles were sectioned to determine the sexuality.

Physical parameters were recorded at the time of each destructive sampling. Salinity was measured using an Atago hand refractometer, water temperature and DO were measured using a salinity compensated dissolved oxygen meter (YSI Model 57), pH was measured using an ATC pH meter (Piccolo 2). Ambient temperature (minimum and maximum air temperatures), mean number of hours of sunshine per day, mean solar radiation and total rainfall for Malacca (2° 16′ N, 102° 15′ E), were obtained from the Malaysian Meteorological Department, Petaling Jaya, Selangor. The protocol for the analysis of nutrients followed the standard method given for ammonia (Solorzano, 1969), nitrate (Isa et al., 1980) and phosphate (Strickland & Parsons, 1968).

Statistical analysis

One way ANOVA was employed to test for any significant difference among the monthly abiotic and biotic data. Data from destructive sampling (biomass, mean thallus length and number of plants bearing receptacles) were correlated with the environmental parameters using Pearson Product Moment correlation analysis. All statistical analyses were conducted using the computer package 'Statgraphic Version 5.0'.

Results

Mean quarterly biomass

The peak biomass of *S. baccularia* population was obtained in January 1995 (520.23 ± 724.37 g WW m^{-2}, 47.88 ± 65.47 g DW m^{-2}, 13.35 ± 16.69 g AFDW m^{-2}) and July 1995 (501.98 ± 341.05 g WW m^{-2}, 64.92 ± 40.99 g DW m^{-2}, 14.00 ± 9.65 g AFDW m^{-2}) (Fig. 2A). The lowest biomass occurred in January 1996 at 76.14 ± 37.97 g WW m^{-2}, 9.97 ± 4.62 g DW m^{-2}, 1.97 ± 1.00 g AFDW m^{-2}. One way ANOVA followed by LSD multiple range test (95% confidence level) denoted a significant difference among the monthly biomass values (WW: df = 30, $F = 16.66$, $p < 0.0001$; DW: df = 30, $F = 7.185$, $p < 0.003$; AFDW: df = 29, $F = 12.060$, $p < 0.0001$).

Biomass of *S. binderi* showed a more distinct unimodal pattern of change within a year (Fig. 2B). The highest value was first obtained in July 1995 (429.28 ± 385.64 g WW m^{-2}, 54.30 ± 50.25 g DW m^{-2}, 11.20 ± 11.43 g AFDW m^{-2}), followed by another peak in the following year in April 1996 (656.13 ± 735.27 g WW m^{-2}, 80.81 ± 76.02 g DW m^{-2}, 15.25 ± 16.72 g AFDW m^{-2}). Biomass was the lowest in January 1996 (68.21±33.08 g WW m^{-2}, 8.36±4.07 g DW m^{-2}, 1.68±0.89 g AFDW m^{-2}). Results of one way ANOVA, followed by LSD multiple range test (95% confidence level), also indicated a significant difference among the monthly biomass values (WW: df = 30, $F = 5.255$, $p < 0.002$; DW: df = 30, $F = 3.228$, $p < 0.022$; AFDW: df = 29, $F = 3.336$, $p < 0.019$).

Comparison between biomass, mean thallus length and percentage fertility

The peak period of the thallus length coincided with the peak period of biomass for both *Sargassum* species (Fig. 2). Correlation analysis indicated *S. baccularia* population to have a strong positive correlation between the mean thallus length and the WW ($r = 0.9826$), DW ($r = 0.8783$) and AFDW ($r = 0.9777$). Similar results were obtained for *S. binderi* population ($r = 0.9275$ for WW, $r = 0.9496$ for DW, $r = 0.8593$ for AFDW).

S. baccularia population recorded extremely low percentage fertility in July 1995 (0.54%) and April 1996 (0.44%), with zero fertility in other sampling periods (Fig. 3A). The fertility of *S. baccularia* population showed a significant ($p \leq 0.05$) positive correlation with WW ($r = 0.6690$), DW ($r = 0.7505$), AFDW ($r = 0.7301$) and mean thallus length ($r = 0.5952$).

S. binderi population was fertile throughout the sampling period with the highest percentage fertility recorded in April 1996 (59.70%) and the lowest in January 1996 (4.17%) (Fig. 3B). The percentage fertility of *S. binderi* population was significantly ($p \leq 0.05$) correlated with WW ($r = 0.7770$), DW ($r = 0.8673$), AFDW ($r = 0.6267$) and mean thallus length ($r = 0.8959$).

Seasonal variation in length classes

The length class distribution of the *S. baccularia* plants was different for every sampling period from January 1995 to April 1996 (Fig. 4). For individuals in this population, those in 50–99 mm length class showed the highest percentage frequency (54%) in January 1995. This gradually decreased to about 20% in July and October 1995 before starting to increase in April 1996 (24%). Within this same period, those in length classes >100 mm increased from around 37% in January 1995 to about 60% in July 1995 before ex-

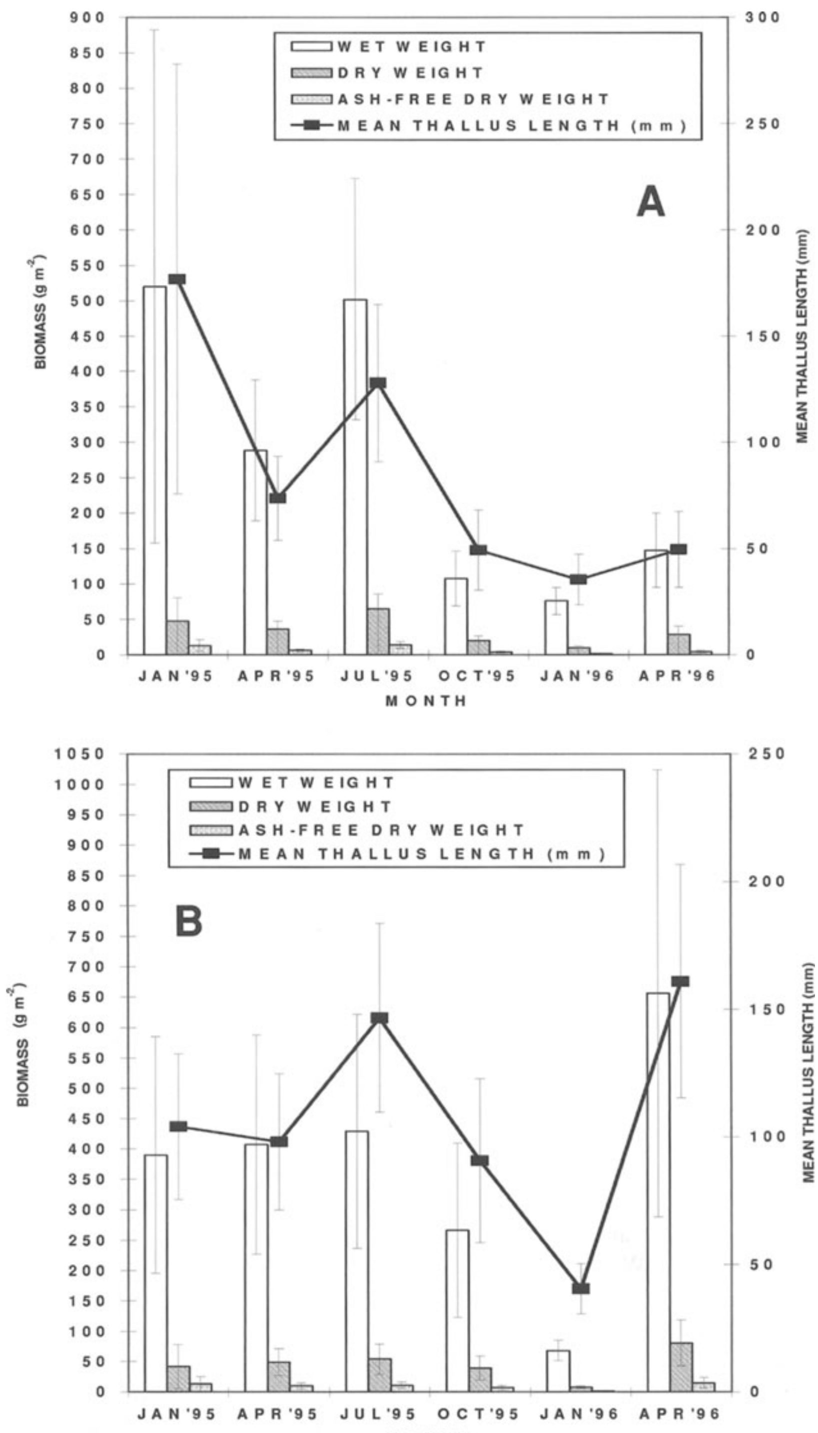

Figure 2. Mean (± SD) thallus length (mm) and biomass (g m^{-2}) of (A) *Sargassum baccularia* and (B) *S. binderi*.

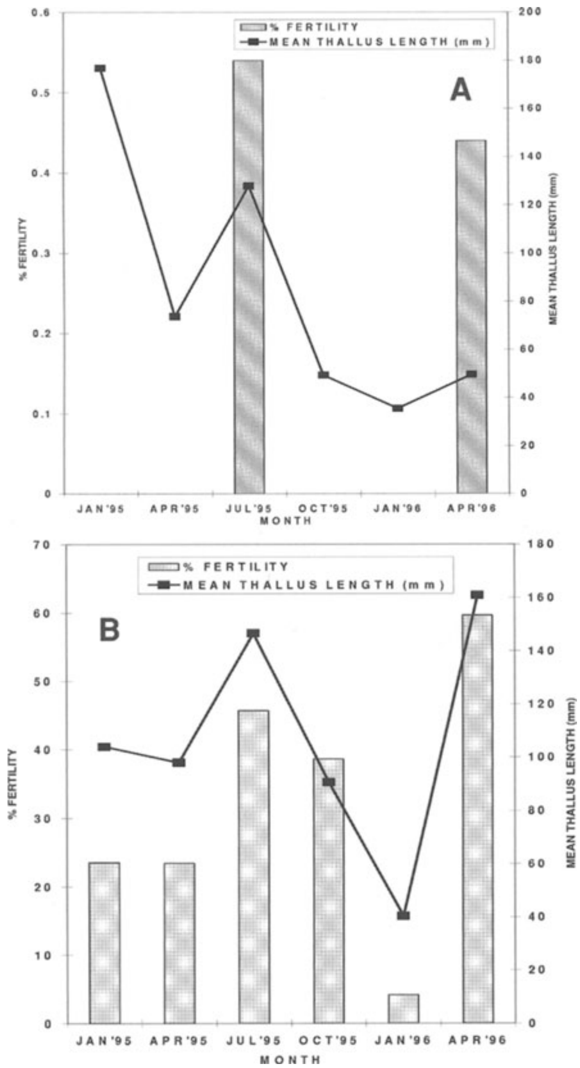

Figure 3. Comparison between percentage fertility and mean thallus length (mm) for (A) *Sargassum baccularia* and (B) *S. binderi.*

periencing a sudden drop to less than 12% in October 1995. Those in the smallest length class (>0–49 mm) showed a reverse trend. In January 1995, percentage frequency for >0–49 mm length class was less than 10% but it gradually increased to about 70% in October 1995 and reached the maximum (80%) in January 1996 before starting to decline again in April 1996. The overall average length of individuals in the population was 65.99 ± 60.32 mm with 54% of these being <49 mm in length.

The length class distribution of the *S. binderi* plants was also different for every sampling period from January 1995 to April 1996 (Fig. 5) although the general trend was similar to that observed for *S. baccularia*. Almost half of the plants were found in the length class of 50–99 mm in January 1995 (47%) and April 1995 (43%). This gradually decreased to 19% in July 1995 and then slightly increased to 25–27% in October 1995 and January 1996 before dropping to 18% in April 1996. The frequency of those in length classes >100 mm increased from 38% in January 1995 to 72% in July 1995 before dropping to 39% in October 1995 and <2% in January 1996. It reached another peak of 71% again in April 1996. Individuals in length class >0–49 mm constituted <16% of the total population from January to July 1995. In October 1995 and January 1996 however, 35% and 71%, respectively, of the plants were found in this smallest length class before dropping to around 10% in April 1996. The overall average length of individuals of *S. binderi* population was 107.24 ± 74.17 mm with 89% of the population <199 mm and 54% <99 mm in length.

Correlation between environmental parameters, biomass, thallus length and fertility

Increase in biomass of *S. baccularia* population was significantly correlated with the increase in rainfall and phosphate level (except for DW) and the decrease in pH and radiation (Table 1). Whereas, increase in biomass of the *S. binderi* population was significantly correlated to the increase in salinity (except for DW and AFDW), water temperature (except for AFDW), ambient temperature, sunshine and rainfall, and decrease in ammonia (except for AFDW) and nitrate levels (Table 1).

Discussion

Both *Sargassum* populations attained two peaks and one low in standing crop over the 15-month quarterly monitored period. The values of the highest standing crop obtained for both species are relatively low (approximately ten times lower) as compared to the standing crop of *Sargassum* species reported in the Philippines (Ang, 1984; Trono & Lluisma, 1990; Largo et al., 1994), but are comparable to those from the earlier studies by Phang (1995) at Cape Rachado, Port Dickson in 1987–1988. The number of plants collected during the peak biomass period for *S. baccularia* in July 1995) and for *S. binderi* in April 1996 were 373 and 67, respectively (Wong, 1997). Although the amounts of standing crop attained for both species were almost the same, the number of

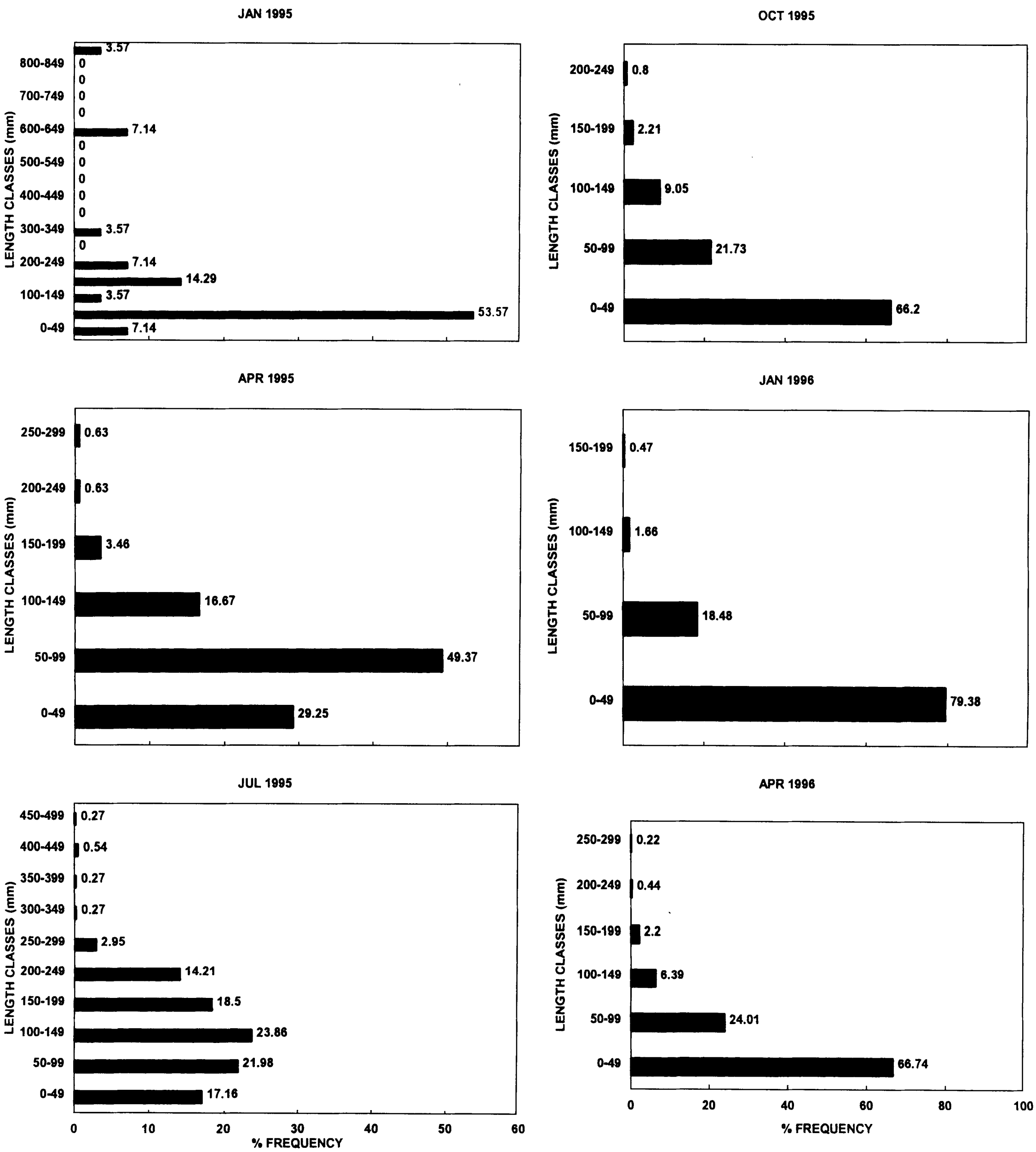

Figure 4. Percentage frequency of length classes of *Sargassum baccularia* in different sampling periods.

plants involved for *S. binderi* was almost six times lower than that for *S. baccularia*. *S. binderi* plants were usually larger and with more lateral branches. They were mostly found farther away from shore and hence were usually submerged in the water even during very low tide. This prevented them from being exposed to severe desiccation stress even when the reef was exposed. Furthermore, the presence of receptacle-bearing lateral branches increased their standing crop. This was also observed by Largo & Ohno (1992), who reported that the standing crop of *S. myriocystum* and *S. siliquosum* in the Philippines increased as the plants became fertile. In contrast to *S. binderi*, *S. baccularia* plants tended to grow near shore where they were usually exposed to the full impact of desiccation.

A strong correlation was found between the standing crop and the mean thallus length as well as the number of plants bearing receptacles for both *Sargassum* species in this present study. The peak thallus length and reproductive period coincided with the peak biomass period. This is a phenomenon typical to *Sargassum* species as reported by various authors

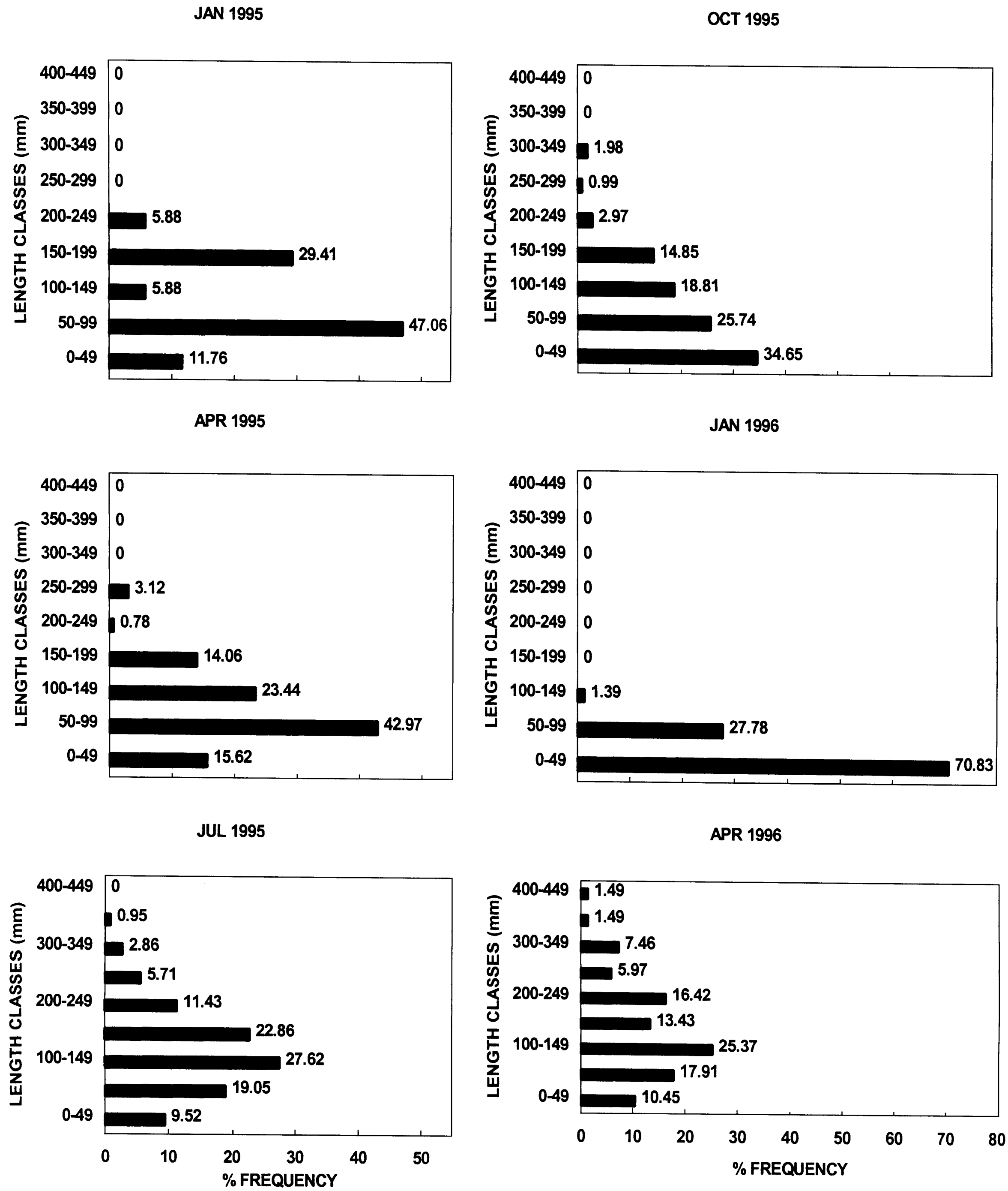

Figure 5. Percentage frequency of length classes of *Sargassum binderi* in different sampling periods.

(Tsuda, 1972; De Wreede, 1976; De Ruyter Van Steveninck & Breeman, 1987).

Mean thallus length for both *Sargassum* species (*S. baccularia* = 66 mm, *S. binderi* = 107 mm) in this study is smaller than what is reported for other species in other countries. Populations of both *Sargassum* species in the present study were exposed to air at low tide. This is especially so for individuals of *S. baccularia* as they were found higher up on the intertidal. For most of the other species studied elsewhere, they are either found in the subtidal environment or in low intertidal, such that exposure to air during low tides happens only occasionally. Exposure to air, especially during daytime low tides, results in loss of water from

Table 1. Correlation between *Sargassum* biomass [wet weight (WW), dry weight (DW), ash free dry weight (AFDW)], mean thallus length (TL) and number of plants bearing receptacles (*F*) with environmental parameters

Environmental parameters	WW	DW	AFDW	TL	*F*
I. *S. baccularia*					
Salinity	0.3679	0.4550	0.2704	0.2044	0.4457
Temperature	−0.2059	0.0959	−0.2010	−0.3179	0.1596
Min Temp.	0.0008	0.1670	−0.0266	−0.0696	−0.0374
Max Temp.	−0.0995	0.0568	−0.1657	−0.2201	0.0364
D.O.	−0.1186	0.0260	−0.0764	−0.0588	−0.4030
pH	−0.6864*	−0.6101*	−0.7391*	−0.7074*	−0.5806*
Radiation	−0.6658*	−0.5962*	−0.7301*	−0.7554*	−0.1822
Sunshine	−0.3553	−0.2434	−0.4174	−0.4766*	0.0588
Rainfall	0.5370*	0.7987*	0.5917*	0.4313	0.7619*
Ammonia	−0.1856	−0.4103	−0.1329	−0.0080	−0.5200*
Nitrate	−0.4543	−0.4821	−0.3931	−0.3482	−0.3722
Phosphate	0.5673*	0.2777	0.5156*	0.6254*	−0.0492
II. *S. binderi*					
Salinity	0.4997*	0.4198	0.4139	0.4236	0.1087
Temperature	0.5798*	0.6775*	0.3632	0.5914*	0.8040*
Min Temp.	0.5669*	0.6229*	0.4857	0.4622	0.6401*
Max Temp.	0.6638*	0.6858*	0.5314*	0.4767	0.4865
D.O.	−0.4027	−0.2797	−0.4782	−0.1778	0.4074
pH	0.0072	0.0831	−0.1643	−0.1666	0.1194
Radiation	0.3234	0.3424	0.1288	0.0718	0.0017
Sunshine	0.6390*	0.6457*	0.4823	0.3888	0.2559
Rainfall	0.7529*	0.7854*	0.7069*	0.9104*	0.8686*
Ammonia	−0.6228*	−0.6105*	−0.4452	−0.6232*	−0.4587
Nitrate	−0.8343*	−0.7700*	−0.8886*	−0.6241*	−0.3370
Phosphate	0.0560	−0.0712	0.3469	−0.1419	−0.4482

*$p < 0.05$.

the thallus. Furthermore, daytime low tides are much more damaging during hot summer. This situation causes desiccation stress to the intertidal seaweeds especially those seaweeds found higher above zero tide level, like S. *baccularia*, where the plants are exposed to desiccation stress for prolonged period of time. This could have restricted the growth of these plants and thus may explain why individuals of *S. baccularia* plants had much shorter mean thallus length than those of *S. binderi*, and both were generally shorter than those of other species reported in other countries.

The highest growth and reproductive activity of *S. binderi* occurred during periods of higher water temperature, but not for *S. baccularia*. The *S. binderi* population behaved more like the *Sargassum* species reported by Tsuda (1972) in Guam, Prince & O'Neal (1979) in Florida, Ang (1985) in the Philippines and De Ruyter Van Stevenick & Breeman (1987) in Curacao, Netherlands Antilles. This is in contrast to the generalisation made by De Wreede (1976) and McCourt (1984), who stated that most tropical *Sargassum* species reached maximum growth and fertility in the cooler months of the year.

Analysis of length class frequency distribution of the two *Sargassum* populations revealed that the populations were mainly made up of small plants during most of the year. Shift in length class distribution was a result of three main processes: growth, die back (degeneration) and recruitment of new individuals. Similar patterns were observed for individuals in both the *S. baccularia* and *S. binderi* populations although the timing may not be the same. The initial shift in dominance from smaller to larger sizes was due to growth of the plants as the maximum growth rate was obtained in June 1995 (Wong, 1997). On the other hand, the highest degenerative rate (die back) was obtained after July 1995 (Wong, 1997). This coincided with the die back of the plants after peak reproduction and contributed to the shift in maximum size frequency of the population to the smallest length class from July 1995 to October 1995. Koh et al. (1993) recorded small size classes of *S. thunbergii* over the whole year in Korea. They pointed out that the occurrence of higher frequency of smaller size class individuals indicated a size reduction of the *S. thunbergii* plant after the growing period. The rapid increase in the dominance of smallest length class after July 1995 must be contributed in part by the recruitment of new and smaller plants. This contribution to shift in the population size structure should be more important in *S. baccularia* than in *S. binderi* as reproductive plants were always present in the latter. Continuous recruitment must be taking plant in the population of *S. binderi* so that new recruits would always contribute to a certain proportion of the individuals in the smallest length class of this population. In contrast, reproduction took place only within a narrow period in *S. baccularia*. Recruits would thus be available only within a few months after reproduction. Hence, for *S. baccularia* population, it is likely that recruits would only contribute mainly to the dominance of the smallest length class 3–6 months after reproduction, i.e. in Oct 1995 and January 1996.

Environmental factors play an important role in affecting the growth of algal populations. In this study, the most important among these factors in affecting the growth of both *Sargassum* populations appears to be rainfall. November is the monsoon month with heavy rain, strong waves and high turbidity (field observation). All of these could be detrimental to the growth of *Sargassum*. Hence, biomass and percentage fertility for both *Sargassum* species were the lowest in January 1996. Most plants would have died, or their annual parts died back in the previous months. Other than rainfall, there may be other factors which contributed to the seasonality of the *Sargassum* populations. Owing to the spatial distribution of *S. baccularia* population, being found mainly in the shallower, shoreward location when compared to the *S. binderi* population, factors like radiation may be more important to *S. baccularia* than to *S. binderi*. This is evidenced by the significant correlation found between radiation and the biomass and thallus length of *S. baccularia* but not with those of *S. binderi*. On the other hand, water temperature appears to be more important to *S. binderi* than to *S. baccularia*.

This study represents the first detailed study of *Sargassum* ecology in Malaysia. Data generated from this study are therefore very important in providing an insight into the growth and production of the two dominant *Sargassum* species found in the west coast of Peninsular Malaysia. Rainfall appears to be the most important factor in influencing the growth of *Sargassum*. Phang & Maheswary (1989) identified some Malaysian *Sargassum* species as potential sources of alginic acid. However, the results from the present study show that the biomass yield is too low to sustain harvesting from the wild populations for an alginate industry.

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