La mer 55 : 11–23, 2017
Société franco-japonaise d'océanographie, Tokyo

Growth and reproductive seasonal pattern of *Sargassum polycystum* C. Agardh (Sargassaceae, Phaeophyceae) population in Samaesarn Island, Chon Buri Province, Thailand

Thidarat NOIRAKSAR[1)]*, Vipoosit MANTHACHITRA[2)], Aunkul BURANAPRATHEPRAT[2)] and Teruhisa KOMATSU[3)]

Abstract: *Sargassum* forests form important habitats in coastal waters worldwide. *Sargassum polycystum* C. Agardh is a dominant species consisting of *Sargassum* forests and distributed widely in the Gulf of Thailand. We studied seasonal variations of *S. polycystum* on the intertidal reef flats in Samaesarn Island off the northeast coast of the Gulf of Thailand by monthly quadrat sampling, observation of *S. polycystum* and measurements of environmental variables from January 2014 to December 2015. Percent cover, thallus length, standing crop, percentages of the numbers of immature and mature plants of *S. polycystum* per 0.25 m^2 were the maximum during the dry and cold season from November to February. They showed a significant negative correlation with water temperature ($p<0.05$) and significant positive correlation with DO and phosphate ($p<0.05$). Percentage of the number of holdfasts, main without stipes of *S. polycystum* per 0.25 m^2, which was the highest in among the numbers of juvenile, immature and mature plants, and main holdfasts without sipes of *S. polycystum* per 0.25 m^2 in March 2014 and December 2015, showed a significant and negative correlation with current speed ($p<0.05$). Plant density, percentage of the number of juvenile plants of *S. polycystum* were the maximum during the rainy season from May to September. These results indicate that the monsoon drives environmental variables controlling the seasonal pattern of the growth and reproduction of *S. polycystum*. Its maturation and reproduction occur under a calm sea condition and low water temperature with sufficient solar radiation in January-February at the end of dry season.

Keywords : *Sargassum polycystum, phenology, Gulf of Thailand; growth*

1. Introduction

Genus, *Sargassum* C. Agardh (Sargassaceae, Phaeophyceae), is the largest genus of the brown algae which is the most ecologically abundant and economically important. *Sargassum* species are distributed in tropical to temperate regions all

1) Institute of Marine Science, Burapha University, Bangsaen, Chon Buri 20131, Thailand
2) Department of Aquatic Science, Faculty of Science, Burapha University, Bangsaen, Chon Buri 20131, Thailand
3) Atmosphere and Ocean Research Institute, The University of Tokyo, 5–1–5, Kashiwanoha, Kashiwa, Chiba 277–8564, Japan
*Corresponding author: Thidarat Noiraksar
Tel: + 66(0)38 391671
Fax: + 66(0)38 391674
E-mail: sargassum2005@gmail.com

over the world (YOSHIDA, 1983). *Sargassum* beds absorb CO_2 and produce O_2 in seawater through photosynthesis. Thus, they influence dissolved oxygen content in seawater (DO) (MIKAMI *et al.* 2007) and consequently pH distributions through changing equilibrium of carbonate in seawater by absorption and release of CO_2 (KOMATSU, 1989; KOMATSU and KAWAI, 1986). They influence downward radiation from the sun through their canopy (KOMATSU *et al.*, 1990), and eventually water temperature distributions inside the *Sargassum* forest (KOMATSU *et al.*, 1982; KOMATSU, 1985, KOMATSU *et al.*, 1995). Their stipes and fronds buffer water motion inside the forest (KOMATSU and MURAKAMI, 1994). Many commercially important species spawn in *Sargassum* beds (*e.g.* sea urchins, abalones, cuttlefish); larvae and juveniles use the beds as nursery grounds. Detached *Sargassum* species from the substrates form drifting seaweeds providing habitats for fishes and attached animals (KOMATSU *et al.*, 2007; KOMATSU *et al.*, 2008). Thus, *Sargassum* beds support biodiversity and are an important habitat for marine animals.

In Thailand, *Sargassum* species were recorded by Reinbold in "Flora of Koh Chang" from the specimens collected by SCHMIDT (1900) during the Danish Expedition to Siam. *Sargassum polycystum* C. Agardh was reported from Koh Kahdat, Trat Province situated on the northeast coast of the Gulf of Thailand for the first time. *S. polycystum* is distributed widely along the Gulf of Thailand (LEWMANOMONT, 1988; NOIRAKSAR *et al.*, 2006; NOIRAKSAR and AJISAKA, 2008). *S. polycystum* has secondary holdfasts that are transformed from a stolon and heavily muricate on main branches (CHIANG *et al.*, 1992; AJISAKA *et al.*, 1995, 1999) (Fig. 1). Normally recruitment of *S. polycystum* populations is maintained by sexual reproduction while its recruitment is also sustained by secondary holdfasts (NOIRAKSAR and AJISAKA, 2008). Although there are some reports about distributions and ecology of *S. polycystum* in some countries, its ecology of Thailand hasn't been fully examined. To conserve *S. polycystum* in Thailand, it is necessary to understand its ecology. This study aims to elucidate growth and reproductive patterns in a natural habitat off northeast coast of the Gulf of Thailand.

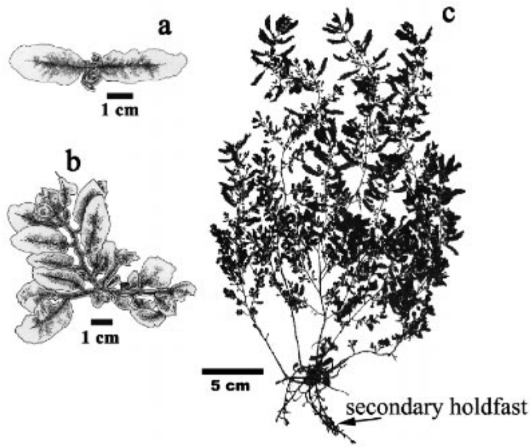

Fig. 1 Thallus stages of *Sargassum polycystum*. **a** juvenile plant, **b** immature plant, and **c** mature plant

2. Materials and methods

2.1 Study site

Samaesarn Island, Chon Buri Province (12°31′21.37″N, 100°57′25.12″E) is surrounded with a large intertidal flat, of which the substratum is composed of rock and dead coral with fine to coarse sand, followed by a subtidal coral reef. This intertidal flat is exposed during the low tide in the day time for about 4–6 hours from April to May (Fig. 2). This island is designated as the conservation area rich in benthic marine algae including four species of *Sargassum* (*S. aquifolium*, *S. oligocystum*, *S. polycystum* and *S. swartzii*) with other seaweeds such as *Turbinaria conoides*, *Padina australis*, *Padina santae-crucis*, *Lobophora*

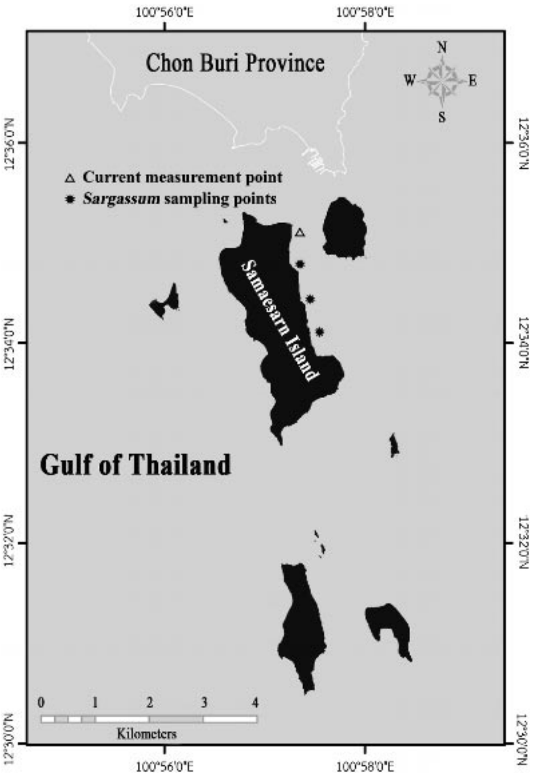

Fig. 2 The study site, on the eastern coast of Samaesarn Island, Chon Buri Province.

asiatica, *L. pachyventera*, *Amphiroa anceps*, *Bryopsis pennata, Gelidiella acerosa*, *Chondrophycus cartilagineus*, etc. Among them, *S. polycystum* is the most dominant species.

2.2 Quadrat sampling of seaweeds and measurements of environmental parameters

Three belt transects, 30 m apart parallel to the shore were set in the *Sargassum* bed (Fig. 2). Quadrats (0.5 x 0.5 m) were placed at 10 m intervals along each line with a length of 120 m starting from a point near an end randomly decided Thirty-six quadrats in total were monitored in each month for a period of 24 months from January 2014 to December 2015. We measured percent covers of all quadrats and collected seaweeds on three quadrats per line in each month. Collected seaweeds were preserved in plastic bags with sodium chloride and brought back to the laboratory at the Institute of Marine Science, Burapha University. The samples were rinsed in fresh water and cleaned of sand and shells. Plant density means the total numbers of juvenile plants, immature plants, mature plants and main holdfasts without stipes of *S. polycystum* on a quadrat (0.5 x 0.5 m). A stipe length of individual *S. polycystum* was measured. Epiphytic plants and aquatic animals attached to an individual were removed before the wet sample was weighed prior to drying in a hot air oven (TS8000 Termaks, Bergen, Norway) at 60℃ for 48 h. Dry weight of each sample was then obtained (CP3202S, Sartorius, Goettingen, Germany) and used for calculating standing crop, which is expressed as the dry weight (g) per unit area.

Three environmental parameters such as water temperature, salinity and DO were recorded at the time of sample collection with a portable multiparameter measuring instrument (YSI 556 MPS, Ohio, USA). Water current was measured by current meters (Valeport Model-105, Valeport Limited, UK) deployed off the study site (Fig. 2). Water samples were collected for the analysis of nutrients (phosphate, nitrate and silicate) using a spectrophotometer (HACH DR 2500, Colorado, USA). Nitrate was measured using cadmium reduction and diazotization method. Phosphate was analyzed by ascorbic acid method. Silicate was analyzed by molybdosilicate method (STRICKLAND and PARSONS, 1972).

2.3 Statistical analysis

A two-way ANOVA was applied to examine differences among characteristics of *S. polycystum* by month and year. Before the ANOVA, standing crop, plant density and thallus length per unit area were transformed using a logarthmic transformation, while percent cover, and percentages of juvenile plants, immature plants, mature plants and main holdfasts in the number of all plants of *S. polycystum* per 0.25 m^2 were transformed using an arcsine transformation. We examined relationships among percent cover, thallus length, standing crop, plant density, percentages of juvenile plants, immature plants, mature plants and holdfasts on the number of all plants of *S. polycystum* per 0.25 m^2 with the eight environmental parameters using Spearman's rank correlation analysis.

3. Results

3.1 Seasonal growth pattern of *Sargassum polycystum*

S. polycystum was monthly found throughout the year for a period of two years. The annual maximum percent covers of *S. polycystum* per unit area in 2014 and 2015 were obtained in January 2014 (66.3 ± 5.4%) and January 2015 (69.0 ± 8.0 %) during the northeast monsoon season from November to February corresponding to the dry season of winter months in the northeast coast of Gulf of Thailand, respectively. The annual minimum percent covers of *S. polycystum* per unit area in 2014 and 2015 occurred in June (4.3 ± 1.4%) and July (4.5 ± 0.8%) during the southwest monsoon season from May to September corresponding to the rainy season of summer months in the northeast coast of the Gulf of Thailand, respectively (Fig. 3). Results of two-way ANOVA (95% confidence level) indicated monthly differences in percent cover of *S. polycystum* per unit area were significant although its interaction of year and months was significant (Table 1).

The annual maximum thallus lengths in 2014 and 2015 were obtained in December 2014 (18.0 ± 3.2 cm) and February 2015 (18.0 ± 2.8 cm) during the dry season, respectively. The annual minimum thallus lengths in 2014 and 2015 occurred in July 2014 (1.6 ± 0.4 cm) and July 2015 (1.1 ± 1.1 cm) during the rainy season, respectively (Fig. 3). Results of two-way ANOVA indicated difference in monthly thallus length of *S. polycystum* was significant although its interaction of year and months was significant (Table 1).

The annual maximum standing crops in 2014 and 2015 were obtained in January (58.23 ± 13.41 g dw. 0.25 m^{-2}) and February (63.15 ± 9.25 g dw. 0.25 m^{-2}) during the dry season, respectively. The annual minimum standing crops in 2014 and 2015 were in July (3.59 ± 0.95 g dw. 0.25 m^{-2}) and July (5.21 ± 1.09 g dw. 0.25 m^{-2}) during the rainy season, respectively (Fig. 3). Results of two-way ANOVA indicated difference in monthly standing crop of *S. polycystum* was significant although its interaction of year and months was significant (Table 1).

The annual maximum plant densities consisting of juvenile plants, immature plants, mature plants and main holdfastsin in 2014 and 2015 were obtained in August (533.2 ± 148.9 no. 0.25 m^{-2}) and August (387.0 ± 78.3 no. 0.25 m^{-2}) during the rainy season, respectively. The annual minimum plant density in 2014 and 2015 occurred in February (102.2 ± 35.9 no. 0.25 m^{-2}) during the dry season and June (108.8 ± 21.9 no. 0.25 m^{-2}) during the rainy season, respectively (Fig. 3). Results of two-way ANOVA indicated difference in monthly plant density of *S. polycystum* was significant although its interaction of year and months was significant (Table 1).

The annual maximum percentages of juvenile plants in 2014 and 2015 were obtained in August (62.9 ± 15.7%) and July (86.3 ± 2.9 %) during the rainy season, respectively. The annual minimum percentages of juvenile plants in 2014 and 2015 occurred in February (3.4 ± 1.4%) and February (15.3 ± 4.7%) during the dry season, respectively (Fig. 4). Results of two-way ANOVA indicated

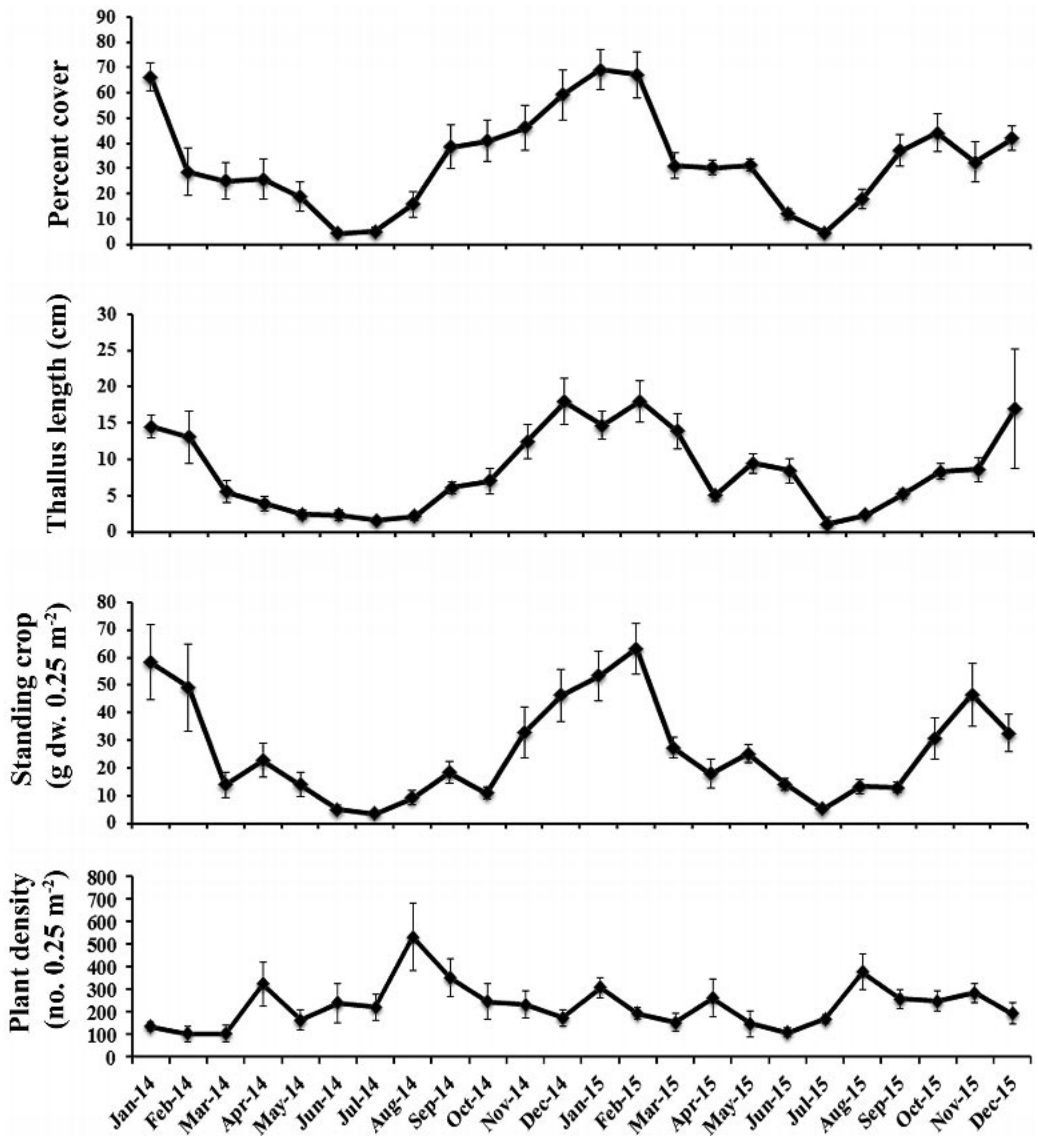

Fig. 3 Percent cover, thallus length, standing crop and plant density of *Sargassum polycystum* (mean ± standard error) in Samaesarn Island, Chon Buri Province from January 2014–December 2015.

difference in monthly percentage of juvenile plants of *S. polycystum* was significant (Table 1).

The annual maximum percentages of immature plants in 2014 and 2015 were obtained in January (87.9 ± 2.2%) and February (61.1 ± 5.4%) during the dry season, respectively. The annual minimum percentages of immature plants in 2014 and 2015 occurred in August (3.2 ± 1.1%) and July (0.5 ± 0.5%) during the rainy season, respectively (Fig.4). Results of two-way ANOVA indicated difference in monthly percentage of immature plants of *S. polycystum* was significant

Table 1. Results of ANOVA testing effects of year and month on percent cover, thallus length, standing crop, plant density, percentages of the numbers of juvenile, immature and mature plants, and main holdfasts without stipes of *Sargassum polycystum* per 0.25 m^2.

Source of variation	Percent coverage of *S. polycystum*				Thallus length of *S. polycystum*			
	df	MS	*F*	*p*	df	MS	*F*	*p*
Year	1	0.099	1.906	0.169	1	0.188	4.206	0.042
Month	11	0.815	15.667	0.000	11	0.818	18.268	0.000
Interaction	11	0.141	2.707	0.003	11	0.182	4.056	0.000
Error	192	.052			163	0.045		
	Standing crop of *S. polycystum*				Plant density of *S. polycystum*			
	df	MS	*F*	*p*	df	MS	*F*	*p*
Year	1	0.012	0.138	0.711	1	0.443	2.844	0.04
Month	11	1.415	16.315	0.000	11	0.417	2.740	0.003
Interaction	11	0.221	2.551	0.005	11	0.415	2.725	0.003
Error	171	0.087			171	0.152		
	Juvenile plants of *S. polycystum*				Immature plants of *S. polycystum*			
	df	MS	*F*	*p*	df	MS	*F*	*p*
Year	1	0.498	6.618	0.011	1	0.045	0.954	0.330
Month	11	1.373	18.257	0.000	11	1.004	21.160	0.000
Interaction	11	0.085	1.133	0.338	11	0.224	4.725	0.000
Error	192	0.075			192	0.047		
	Mature plants of *S. polycystum*				Holdfasts of *S. polycystum*			
	df	MS	*F*	*p*	df	MS	*F*	*p*
Year	1	0.015	1.058	0.305	1	0.195	15.641	0.000
Month	11	0.031	2.179	0.017	11	0.086	6.887	0.000
Interaction	11	0.018	1.248	0.258	11	0.031	2.520	0.005
Error	192	0.014			192	0.012		

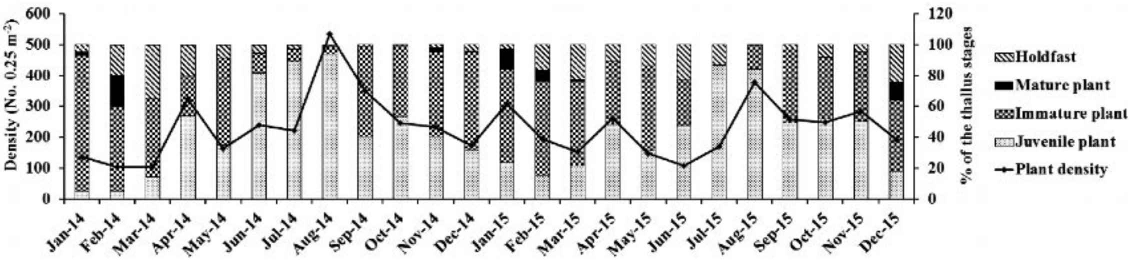

Fig. 4 Percentage of plant stages and density of *Sargassum polycystum* in Samaesarn Island, Chon Buri Province from January 2014 to December 2015

although its interaction of year and months was significant (Table 1).

The annual maximum percentage of mature plants in 2014 and 2015 were obtained in February (13.6 ± 5.0%) and January (13.4 ± 6.1 %) during the dry season, respectively (Fig. 4). There was a low percentage of mature plants between March and November in 2014 and 2015. Results of two-way ANOVA, indicated difference in monthly percentage of mature plants of *S.*

polycystum was significant (Table 1).

The annual maximum percentage of main holdfasts in 2014 and 2015 were obtained in March (23.4 ± 7.5%) during the first inter-monsoon and December (24.5 ± 10.0 %) during the dry season, respectively. There was a low percentage of holdfasts during the rainy season (Fig. 4). Results of two-way ANOVA, indicated differences between year and among months were significant although its interaction of year and months was significant (Table 1).

3.2 Relationships between the features of plant and environmental variables

The monthly average measurements of environmental parameters were shown in Fig. 5. The annual highest water temperatures in 2014 and 2015 were measured in May (31.2℃) and May (31.0℃) during the rainy season, respectively, and the annual lowest water temperatures in 2014 and 2015 were in December (27.4℃) and December (27.2℃) during the dry season, respectively. The annual highest salinities in 2014 and 2015 were observed in October (35.1) during the second inter-monsoon and July (35.3) during the rainy season, respectively, and the annual lowest salinities in 2014 and 2015 were in November (32.0) and January (30.4) during the dry season, respectively. The annual highest DOs in seawater in 2014 and 2015 were observed in December (7.3 mg l^{-1}) and February (8.21 mg l^{-1}) during the dry season, respectively, and the annual lowest DOs in 2014 and 2015 were in July (4.22 mg l^{-1}) and July (4.13 mg l^{-1}) during the rainy season, respectively. The annual highest Phosphate contents in seawater in 2014 and 2015 were observed in October (0.12 mg l^{-1}) during the second inter-monsoon season and July (0.21 mg l^{-1}) during the rainy season, respectively, and the annual lowest phosphate contents were in March (0.02 mg l^{-1}) during the first inter-monsoon season and May (0.03 mg l^{-1}) during the rainy season, respectively. The annual highest nitrate contents in seawater in 2014 and 2015 were observed in July (1.15 mg l^{-1}) and July (1.53 mg l^{-1}) during the rainy season, respectively, and the annual lowest nitrate contents in 2014 and 2015 were in April (0.73 mg l^{-1}) during the first inter-monsoon season and August (0.6 mg l^{-1}) during the rainy season, respectively. The annual highest silicate contents in seawater in 2014 and 2015 were observed in June (4.73 mg l^{-1}) and July (5.53 mg l^{-1}) during the rainy season, respectively, and the annual lowest silicate contents in 2014 and 2015 were in January (1 mg l^{-1}) and December (1.1 mg l^{-1}) during the dry season, respectively. In general, silicate and phosphate contents in seawater were increased during the rainy season except December 2014 for phosphate. The annual highest water currents in 2014 and 2015 were observed in July (38.3 cm s^{-1}) and September (33.1 cm s^{-1}) during the rainy season, respectively, and the annual lowest water currents in 2014 and 2015 were in March (14.2 cm s^{-1}) during the first inter-monsoon season and July (10.8 cm s^{-1}) during the rainy season, respectively.

A spearman's rank-order correlation was applied to determine the relationship between the characteristics of *S. polycystum* and environmental variables (Table 2). There was a significant negative correlation between water temperature and characteristics of *S. polycystum* such as percent cover (r_s= 0.569, p =0.004), thallus length (r_s= 0.630, p = 0.001), standing crop (r_s= 0.583, p = 0.003), percentage of immature plants (r_s= 0.469, p = 0.021) and percentage of mature plants (r_s = 0.496, p = 0.014). On the other hand, the water temperature was positively correlated with percentage of juvenile plants (r_s = 0.496, p=0.014). The salinity negatively and significantly correlated with the percent cover (r_s= 0.424, p

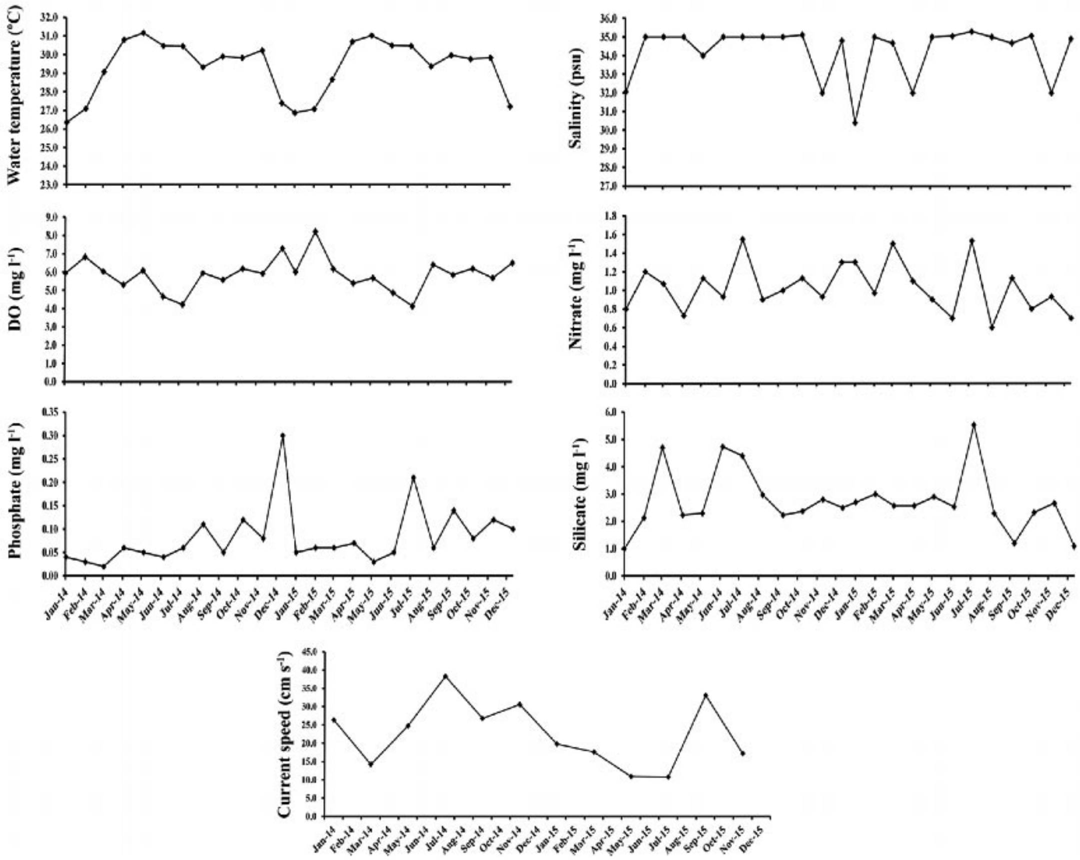

Fig. 5 Environmental variables of seawater measured off the east coast of Samaesarn Island from January 2014 to December 2015.

= 0.039), standing crop (r_s = 0.463, p = 0.023), percentage of immature plants (r_s = 0.522, p = 0.009) and percentage of mature plants (r_s = 0.429, p = 0.036). The DO significantly and positively correlated with percent cover (r_s = 0.539, p = 0.007), thallus length (r_s = 0.602, p = 0.002), standing crop (r_s = 0.504, p = 0.012), percentage of immature plants (r_s = 0.431, p = 0.035) or percentage of mature plants (r_s = 0.518, p = 0.009), while it negatively correlated with percentage of juvenile plants (r_s = 0.470, p = 0.020). The phosphate content significantly and positively correlated with plant density (r_s = 0.416, p = 0.043) or percentage of juvenile plants (r_s = 0.482, p = 0.017). The current speed significantly and negatively correlated with percentage of holdfasts (r_s = 0.790, p = 0.002).

4. Discussion

Monsoon is a very important forcing that controls ecology of seaweed in Southeast Asia. Southwest monsoon from May to September accompanies strong waves with rain while northeast monsoon from November to February accompanies a calm sea condition with sunshine and low water temperature in the northeast coast of the Gulf of Thailand (Fig. 5). The first inter-monsoon season from March to April is also a

Table 2. Significant of Spearman's rank correlation between analysis between environmental parameters and the characteristics of *Sargassum* plant.

S. polycystum	Water temperature (℃)		Salinity (psu)		DO (mg l^{-1})		Phosphate (mg l^{-1})		Current speed (cm s^{-1})	
	r_s	p	r_s	p	r_s	p	r_s	p	r_s	p
% cover	−0.569	0.004**	−0.424	0.039*	0.539	0.007**	0.185	0.387	0.315	0.319
Thallus length	−0.630	0.001**	−0.367	0.078	0.602	0.002**	−0.048	0.823	−0.028	0.931
Standing crop	−0.583	0.003**	−0.463	0.023*	0.504	0.012*	−0.103	0.631	−0.119	0.713
Plant density	0.091	0.671	−0.108	0.614	−0.144	0.501	0.416	0.043*	0.392	0.208
% juvenile plants	0.444	0.030*	0.367	0.078	−0.470	0.020*	0.482	0.017*	0.126	0.697
% immature plants	−0.469	0.021*	−0.522	0.009**	0.431	0.035*	0.014	0.948	0.224	0.484
% mature plants	−0.496	0.014*	−0.429	0.036*	0.518	0.009**	−0.200	0.348	0.037	0.908
% holdfasts	0.015	0.944	0.088	0.684	0.074	0.731	−0.232	0.274	−0.790	0.002**

** $p = 0.01$; * $p = 0.05$

Table 3. Periods of *Sargassum polycystum* growth, reproduction and degeneration phases at Samaesarn Island from January 2014 to December 2015

Plant stages	Timing
Growth	January 2014
Reproduction	January-February 2014
Degeneration	February-July 2014
Growth	August 2014-February 2015
Reproduction	November 2014-Februaty 2015
Degeneration	March-July 2015
Growth	August-December 2015
Reproduction	December 2015
Degeneration	December 2015

calm sea condition. Phenology of *Sargassum* species may be controlled with water temperature strongly related to the monsoon because water temperature is one of the most critical factors affecting the phenological patterns of *Sargassum* species (Ang, 2006). It is speculated that warm surface water is accumulated along the northeast coast of the Gulf of Thailand by the southwest monsoon from May to September and cold surface water is supplied by the coastal upwelling along the northeast of the Gulf of Thailand driven by the northeast monsoon from November to February.

In the Philippines, the dry and wet seasons are from January to May and from June to December, respectively. Trono and Lluisma (1990) studied *Sargassum* populations at Santiago Island, Bolinao and reported that thallus length and fertility of *S. polycystum* attained the highest in December (447 g wet wt m^{-2}) and in January or February, respectively, before the sudden reduction in standing crop. Investigating *Sargassum* beds in Bolinao, Trono and Tolentino (1993) reported that the maximum standing crops of both intertidal and subtidal *Sargassum* beds were obtained in October to December or January, and the reproductive period was from November to January during the cold season there. Largo *et al.* (1994) examined the seasonal changes in the growth and reproduction of S*argassum* species in Liloan, Cebu, and found that the maximum thallus length of *S. polycystum* was in January (30.0 ± 11.4 cm), and its reproductive period was from December to January and February to May during the dry season. Ohno *et al.* (1995) reported *S. polycystum* at Danajon Reef, the Central Visayas area had a mean standing crop of 4.3 kg m^{-2} with the maximum one of 9.6 kg m^{-2} in December. Calumpong *et al.* (1999) reported the maximum standing crop and percent cover of *S. polycystum* in Negro Island were in May (11.3 ± 0.5 g m^{-2}, 10–15%), and the reproductive stage was found from March to May. Thus, the reproductive period and the months of the maximum standing crop of *S. polycystum* range in the dry and cold season in the Philippines like those in Samaesarn Island.

In Taiwan, HWANG *et al.* (2004) reported percent cover and standing crop of *S. polycystum* decreased with increasing water temperature in coral reef in Nanwan Bay. They also stated that its reproductive stage was in January-April during the dry and cold season. In Malaysia, MAY-LIN and CHING-LEE (2013) studied *S. polycystum* at Teluk Kemang, Port Dickson, of which dry season is from June to September, and reported that the pattern of mean thallus length (MTL) and the maximum fertilities showed the highest in July 2010 (MTL = 228 mm, largest length class within 800–899 mm) and in August 2010 (17%), respectively. In India, Rao (2002) reported that the growth of *S. polycystum* attained its maximum length in the winter months (November to December/ January) and *S. polycystum* became reproductive between November and February in Visakhapatnam coast, east India, of which dry season is from November to March. The seasonal growth cycle in *S. polycystum* showed a significant negative correlation with seawater temperature. PADAL *et al.* (2014) verified the same tendency in Visakhapatnam coast as the same as Rao (2002). The maximum mean length, maximum fertilities and reproductive stage of *S. polycystum* occur in dry season when the sea is calm and seawater temperature is low in Taiwan, Malaysia and India. Thus, it is reasonable that those of *S. polycystum* in Samaesarn Island do from December to February in the dry season and March in the inter-monsoon season when the sea is calm and seawater temperature is low.

For reproduction of *S. polycystum*, the thalli must become the longest in a year. The longer the thallus length is, the stronger the drag force posed by waves is (XU and KOMATSU, 2016). Therefore, maturation period must be under a calm condition. In the study area, the northeast monsoon season from November to February and the first inter-monsoon season from March to April are calm sea condition. Since the northeast monsoon season is dry season, the solar radiation is sufficient for photosynthesis of *S. polycystum* to acquire energy to prepare reproduction with elongation of its thalli.

Percentage of holdfasts was low in the rainy season and showed a significant and negative correlation with current speed ($p < 0.05$). In general, main branches and stipes of *Sargassum* species are damaged by strong waves in the monsoon season and remained only holdfasts. The *Sargassum* plants were damaged by the strong water motion (LARGO *et al.*, 1994). The study area is affected by the southwest monsoon from May to October. In the northeast coast of the Gulf of Thailand, southwest monsoon produces greater waves with fetch longer than in northeast monsoon season. Therefore, the onset of southeast monsoon removes large thallus after the luxuriant growth in February. DO is also influenced by stratification of surface layer. Since southwest monsoon brings warm water in the northeast coast of the Gulf of Thailand, it is possible that the stratification is strengthened and eventually DO is decreased. Therefore, DO was higher in the dry season and lower in the rainy season. This phenomenon coincides with higher percent cover, thallus length, standing crop, percentage of immature plants and percentage of mature plants of *S. polycystum* that provide O_2 through photosynthesis to seawater-during the dry season from November to February. Therefore, they are apparently correlated to DO.

Phosphate and nitrate might be increased with increase in discharge from the river to the Gulf of

Thailand during the rainy season in east Gulf of Thailand. Hwang *et al.* (2004) stated that phosphate limits growth of *Sargassum* germlings. This hypothesis may be applied to a positive relation between phosphate, and plant density or percentage of juvenile plants.

S. polycystum existed throughout the year in Samaesarn Island, Chon Buri Province in the Gulf of Thailand as in the Philippines (TRONO and LLUISMA, 1990; CALUMPONG *et al.*, 1999), Malaysia (MAY-LIN and CHING-LEE, 2013) and India (RAO, 2002; PADAL *et al.*, 2014). This means that *S. polycystum* is a perennial species that can regenerate new stipes from a persistent rhizoidal holdfast. Many young *S. polycystum* consisting of juvenile and immature plants constituted a population.

A typical growth cycle in *Sargassum* species is characterized by presence of a slow growth phase, a rapid growth phase, and a reproductive phase that is followed by senescence and dieback (ANG, 2006). In the present study, we can summarize the phenology of *S. polycystum* to three periods of growth, reproduction and degeneration in a year (Table 3).

Present study shows the variations of environmental factors and growth patterns of *S. polycystum* from the northeast coast of the Gulf of Thailand. The monsoon drives environmental variables such as water temperature, sunshine, calm sea condition, etc. which influence seasonal variations of growth, reproduction and degeneration of *S. polycystum*. Reproduction of *S. polycystum* occurs under the calm condition during the dry and cold season. In this way, seasonal growth and reproduction are controlled by the monsoon in the northeast coast of the Gulf of Thailand.

Acknowledgments

We are deeply indebted to the sponsors of this study which was conducted under the National Science and Technology Development Agency (NSTDA). Our thanks go to Plant Genetic Conservation Project Under the Royal Initiation of Her Royal Highness Princess Maha Chakri Sirindhorn (RSPG); Naval Special Warfare Command, Royal Thai Navy; Institute of Marine Science and Faculty of Science, Burapha University; Atmosphere and Ocean Research Institute, The University of Tokyo; School of Marine Biosciences, Kitasato University; the Asian CORE Program of the Japan Society for the Promotion of Science, Establishment of research and education network on coastal marine science in Southeast Asia; and Core-to-Core Program, of the Japan Society for the Promotion of Science, Research and Education Network on coastal ecosystems in Southeast Asia (RENSEA) for their supports.

References

AJISAKA, T., PHANG, S. M. and YOSHIDA, T. (1999): Preliminary report of *Sargassum* species collected from Malaysian coasts. *In* Taxonomy of Economic Seaweeds with Reference to Some Pacific Species vol. 7. ABBOTT, I. A. (ed.), California Sea Grant College, La Jolla, p. 23–41.

AJISAKA, T., NORO, T. and YOSHIDA, T. (1995): Zygocarpic *Sargassum* species (Subgenus *Sargassum*) from Japan. *In* Taxonomy of Economic Seaweeds with Reference to Some Pacific Species vol. 5. ABBOTT, I. A. (ed.), California Sea Grant College, La Jolla, p. 11–44.

ANG, P. O. Jr. (2006): Phenology of *Sargassum* spp. in Tung Oing Chau Marine Park, Hong Kong, SAR, China. J. Appl. Phycol., **18**, 629–636.

CALUMPONG H. P., MAYPA, A. P. and MAGBANUA, M. (1999): Population and alginate yield and quality assessment of four *Sargassum* species in Negros Island, Central Philippines. Hydrobiol., **398–399**, 211–215.

CHIANG, Y-M, YOSHIDA, T., AJISAKA, T., TRONO, G. C. Jr., TSENG, C. K. and LU, B. (1992): Distribution and variation in *Sargassum polycystum* C. Agardh (Fucales, Phaeophyta). *In* Taxonomy of Economic Seaweeds with Reference to Some Pacific and Western Atlantic Species vol. 3, ABBOTT, I.A. (ed.), California Sea Grant College, p. 35–42.

HWANG, R. L., TSAI, C. C. and LEE, T. M. (2004): Assessment of temperature and nutrient limitation on seasonal dynamics among species of *Sargassum* from a coral reef in Southern Taiwan. J. Phycol., **40**, 463–473.

KOMATSU, T. (1985): Temporal fluctuations of water temperature in a *Sargassum* forest. J. Oceanogr. Soc. Jpn., **41**, 235–243.

KOMATSU, T. (1989): Day-night reversion in the horizontal distributions of dissolved oxygen content and pH in a *Sargassum* forest. J. Oceanogr. Soc. Jpn., 45, 106–115.

KOMATSU, T. and KAWAI, H. (1986): Diurnal changes of pH distributions and the cascading of shore water in a *Sargassum* forest, J. Oceanogr. Soc. Jpn., **42**, 447–458.

KOMATSU, T. and MURAKAMI, S. (1994): Influence of a *Sargassum* forest on the spatial distribution of water flow. Fish. Oceanogr., **3**, 256–266.

KOMATSU, T., ARIYAMA, H., NAKAHARa, H. and SAKAMOTO, W. (1982): Spatial and temporal distributions of water temperature in a *Sargassum* forest. J. Oceanogr. Soc. Jpn, **38**, 63–72.

KOMATSU, T., KAWAI, H. and SAKAMOTO, W. (1990): Influences of *Sargassum* forests on marine environments. Bull. Coast. Oceanogr., **27**, 115–126. (in Japanese with English abstract).

KOMATSu, T., MATSUNAGA, D., MIKAMI, A., Sagawa, T., Boisnier, E., Tatsukawa, K., Aoki, M., Ajisaka, T., UWAI, S., TANAKA, K., ISHIDA, K., TANOUE, H. and SUGIMOTO, T. (2008): Abundance of drifting seaweeds in eastern East China Sea. J. Appl. Phycol., **20**, 801–809.

KOMATSU, T., MURAKAMI, S. and KAWAI, H. (1995): Some features of jump of water temperature in a *Sargassum* forest. J. Oceanogr., **52**, 109–124.

KOMATSU, T., TATSUKAWA, K., FILIPPI, J.-B., SAGAWA, T., MATSUNAGA, D., MIKAMI, A., ISHIDA, K., AJISAKA, T., TANAKA, K., AOKI, M., WANG, W. D., LIU, H. F., ZHANG, S. Y., ZHOU, M. D. and SUGIMOTO, T. (2007): Distribution of drifting seaweeds in eastern East China Sea. J. Mar. Syst., **67**, 245–252.

LARGO, D. B., OHNO, M. and CRITCHLEY, A. T. (1994): Seasonal changes in the growth and reproduction of *Sargassum polycystum* C. Ag. and *Sargassum siliquosum* J. Ag. (Sargassaceae, Fucales) from Liloan, Cebu, in Central Philippines. Jpn. J. Phycol., **42** (1), 53–61.

LEWMANOMONT, K. (1988): Marine algae of coral reefs of Thailand. Thai Fish. Gazette, **41** (6), 561–568.

MAY-LIN, B. Y. and CHING-LEE, W. (2013): Seasonal growth rate of *Sargassum* species at Teluk Kemang, Port Dickson, Malaysia. J. Appl. Phycol., **25** (3), 805–814.

MIKAMI, A., KOMATSU, T., AOKI, M. and SAGAWA, T. (2007): Biomass estimation of a mixed-species *Sargassum* forest using aerial photography, field survey and Geographical Information Systems. *In* GIS/spatial analyses in fisheries and aquatic sciences. Volume 3. NISHIDA, T., P.J. KAIOLA and A.E. CATON (eds.), Fishery-Aquatic GIS Research Group, Saitama. p. 147–160.

NOIRAKSAR, T. and AJISAKA, T. (2008): Taxonomy and distribution of *Sargassum* (Phaeophyceae) in the Gulf of Thailand. J. Appl. Phycol., **20**, 963–977.

NOIRAKSAR, T., AJISAKA, T. and KAEWSURALIKHIT, C. (2006): Species of *Sargassum* in the east coast of the Gulf of Thailand. ScienceAsia, **32** (Sup. 1): 99–106.

OHNO, M., LARGO, D. B. and TRONO, G. C. Jr. (1995): A survey of standing crop, lengths of primary lateral branches and reproductive states of *Sargassum* communities on the reefs of the Philippine Islands. Bull. Mar. Sci. Fish., Kochi University, **15**: 67–78.

PADAL, S. B., RAO, D. A. and SUBBARANGAIAH, G. (2014): Habitat influences the seasonal growth, fruiting behaviour in *Sargassum polycystum* C. Agradh. (Fucales, Phaeophyceae) at Visakhapatnam coast, India. Int. J. Pharm. Bio-Sci., **1** (1), 1–8.

RAO, A. S. (2002): Seasonal growth pattern in *Sargassum polycystum* C. Agradh. (Phaeophyta, Fucales) occurring at Visakhapatnam, east coast of India. Indian J. Mar. Sci., **3** (1), 26–33.

SCHMIDT, J. (1916): Flora of Koh Chang. Contributions to the knowledge of the vegetation in the Gulf of Siam. Bianco Luno, Copenhagen, 498 pp.

STRICKLAND, J. D. H. and PARSONS, T. R. (1972): A practical handbook of seawater analysis. Second Edition, Bulletin 167. Fisheries Research Board of Canada, Ottawa, 310 pp.

TRONO, G. C. Jr. and LLUISMA, A.O. (1990): Seasonality of standing crop of a *Sargassum* (Fucales, Phaeophyta) bed in Bolinao, Pangasinan, Philippines. Hydrobiol., **204/205**, 331–338.

TRONO, G. C. Jr. and TOLENTINO, G. L. (1993): Studies on the management of *Sargassum* (Fucales, Phaeophyta) bed in Bolinao, Pangasinan, Philippines. Kor. J. Phycol., **8** (2), 249–257.

YEONG, B. M. and WONG, C. L. (2012): Three months' monitoring of environmental factors, biomass, length and size classes variation of *Sargassum* species at Cape Rechado, Port Dickson. Pertanika J. Trop. Agri. Sci., **35** (3), 623–630.

YOSHIDA, T. (1983): Japanese species of *Sargassum* subgenus *Bactrophycus* (Phaeophyta, Fucales). J. Fac. Sci., Hokkaido Univ., Series V (Botany), **13**, 99–246.

XU, M. and KOMATSU, T. (2016): Field measurement of drag force on *Sargassum horneri* (Turner) C. Agardh towed by a boat and estimation of its drag coefficient. La mer, **54**, 77–86.

Received: December 9, 2016
Accepted: January 13, 2017