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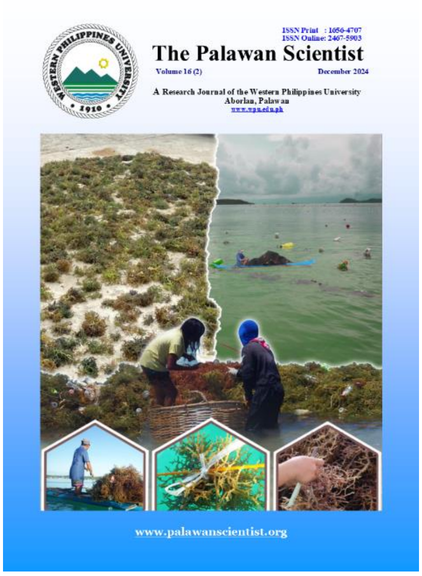

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Selection of fast-growing seaweed cultivars in Palawan, Philippines

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ABSTRACT

Seaweed farming in Palawan currently involves different local cultivars. At least 12 of these cultivars were successfully grown in an indoor facility employing the branch culture techniques and were sea-out planted in Puerto Princesa Bay since 2015. Six of these cultivars yielded relatively high daily growth rates and were selected for the year-round field-testing experiment to compare the growth rates among cultivars and species, between farming sites, and across seasons from July 1, 2021 until August 15, 2022. Monitoring of cultivars' daily growth rates (DGRs) was conducted in 100 m^2 experimental floating monoline plots in Green Island and Sitio Amogues of the municipalities of Roxas and Taytay, Palawan, respectively. Findings revealed that seaweed DGRs significantly varied among cultivars and species ($p = 0.001$; $p = 0.008$). The "spinosum" brown from Puerto Princesa and "sacol" green from Green Island, Roxas had higher DGRs, 4.28% and 4.10%, respectively. Grouping the cultivars per species, the cultivars of *Eucheuma denticulatum* (L. Burmann) Collins & Hervey had higher DGRs compared to *Kappaphycus striatus* (F. Schmitz) L. M. Liao and *Kappaphycus alvarezii* (Doty) L. M. Liao. Spatial and seasonal variabilities in cultivar DGRs were also evident. Four cultivars obtained significantly different DGRs between planting sites. The "tambalang" ($p = 0.010$) and "magnolia" ($p = 0.006$) with DGRs of 3.26% and 4.08%, respectively in Green Island Roxas, while the "spinosum" brown from Puerto Princesa ($p < 0.001$; 4.86% DGR) and San Vicente ($p < 0.001$; 4.45% DGR) in Amogues, Taytay. Three cultivars in Green Island, Roxas, obtained significantly higher DGRs during the wet season. These were the "tambalang" ($p = 0.000$; 3.98% DGR), "magnolia" ($p = 0.000$; 4.57% DGR), and "spinosum"-brown from Puerto Princesa ($p = 0.006$; 5.23% DGR). In Amogues, Taytay, all six cultivars obtained significantly higher DGRs during the wet season: "tambalang" ($p = 0.210$; 3.17% DGR); "lakatan" ($p = 0.004$; 2.69% DGR); "spinosum" brown from Puerto Princesa ($p = 0.00$; 3.97% DGR); and San Vicente ($p = 0.00$; 3.39% DGR). A cropping calendar that indicates the fast-growing cultivars to be planted at a particular site and season is provided in this study. This information shall aid local farmers in cultivar selection towards a sustainable seaweed farm management in Palawan.

Keywords: cultivation, daily growth rates, farmers, planting sites, seasons.

INTRODUCTION

Palawan has accounted for a major share of seaweed production in the Philippines. Holding an annual average record of 370,000 MT from 1997–2021, the area represents 84% of Region 4B's seaweed production, or 20% of the entire Philippines. (PSA 2021). Approximately 5,567 ha of *Kappaphycus* and *Eucheuma* farms can be found in 23 seaweed-producing municipalities in the province (Quiaoit et al. 2018). Year-round production was reported for the municipalities of Agutaya, Cuyo-Magsaysay, Cagayancillo, Balabac, and the Calamian Group of Islands, benefiting 7,604 coastal dwellers in the island province of Palawan (BFAR 2022).

The success of seaweed farming in the province is not without challenges. From 2004 to 2007, annual average production was at 360,378.00 MT. In the succeeding years, 2008 to 2012, the volume increased to 455,473.00 MT, and in the most recent years, 2013 to 2021, only 326,832 MT, or a decrease of 20.8% from the previous years (PSA 2021). Aside from extensive die-offs on farms due to ice-ice disease (Zabala and Gonzales-Plasuz 2020), the scarcity of stable supply of quality seedlings is also a limiting factor to seaweed farm productivity in Palawan (PEMSEA 2016).

To initially address the problem of shortage and decreasing quality of farmed *Kappaphycus* and *Eucheuma*, the Department of Science and Technology-Philippine Council for Agriculture, Aquatic, and Natural Resources Research Division (DOST-PCAARRD) launched the Seaweed Research and Development Program in 2014. One of the outputs of the program is the establishment of seaweed culture facilities at Palawan State University, Tiniguiban, Puerto Princesa City, Palawan. Currently, the facility houses 20 cultivars of commercially farmed seaweeds from different sites, mostly from Palawan. Six of these cultivars have been successfully maintained through branch culture technology in the laboratory and underwent cultivation at various sea-based nurseries in Palawan (Dangan-Galon, unpublished data). With the increasing demand for quality seedlings (Roleda et al. 2021), this study attempted to determine the growth performance of the six successfully cultured cultivars to select better planting materials on farms while new or novel strains of genetically viable seedlings are not yet available for large-scale farming or production.

The selection of fast-growing crops is a promising approach in seaweed aquaculture. This approach was done with 23 morphotypes of farmed seaweeds, which isolated, at that time, *Kapppaphycus alvarezii* (Doty) L.M. Liao as a fast-growing and disease-resistant species among other farmed seaweeds (Doty and Alvarez 1975). The other two widely farmed species, the *Kappaphycus striatus* (Schmitz) L.M. Liao, and *Eucheuma denticulatum* (L. Burmann) Collins & Hervey were also products of the 1996 crop selection program (Ask and Azanza 2002). From these species, the 61 named seaweed cultivars have since been used. The term cultivars were coined by seaweed farmers to refer to crops grown on farms. Cultivars are different from "varieties," which pertain to an identity of taxonomic differentiation (Dumilag et al. 2023).

The measurement of seaweed growth rates to select quality cultivars has been performed in different countries of Asia and in Brazil and South Africa (Simatupang et al. 2021; Rama Rama et al. 2018; Tandel et al. 2017; Kotiya et al. 2011; de Paula et al. 2002; Gerung and Ohno 1997; Ohno et al. 1994). In the Philippines, studies to select fast-growing cultivars have been done mostly in Bohol, Pangasinan, Zamboanga City, Sulu, and Lanao del Norte (Orbita 2013; Hurtado et al. 2012; Borlongan et al. 2011; Luhan and Sollesta 2010; Naguit et al. 2009; Trono et al. 2000; Dawes et al. 1994; Trono and Luisma 1992; Trono and Ohno 1989; Doty 1987; Parker 1974). In most of these studies, variabilities in the growth performance of *Kappaphycus* and *Eucheuma* in relation to species and cultivar types, seasons, and planting sites were recorded.

METHODS

Study Sites and Experimental Species

The branch culture of seaweed cultivars is maintained at Palawan State University-Marine Science Research Center (PSU-MSRC), Tiniguiban, Puerto Princesa City (9º46'32.0" N; 118º43'58.0" E). The field-testing sites were located in Green Island, Tumarbong, Roxas (10º15'46.9" N; 119º29'31.0" E), and Sitio Amogues, Calawag Bay, Taytay, Palawan (10º43'03.1" N; 119º36'16.5" E) (Figure 1). The planting site in Green Island, Roxas, is nearshore-exposed with an average sea surface temperature of 30ºC and salinity of 36‰. The dissolved Oxygen was 4.9 mg. L^{-1}. In Amogues, Taytay, the farm is nearshore-sheltered, with an average sea surface temperature of 31ºC, salinity of 35‰, and dissolved Oxygen of 5.5 mg. L^{-1}.

The six cultivars being cultured at PSU-MSRC and vegetatively cultivated in Puerto Princesa Bay were used in this study. These included the *Kappaphycus alvarezii* cultivar "tambalang" from the land-based seaweed culture facility of the Bureau of Fisheries and Aquatic Resources (BFAR) in Giuan, Samar (May 14, 2014); "lakatan" from Maranggas, Bataraza, collected on February 14, 2020; *Kappaphycus striatus* cultivars "sacol green" and "magnolia" from Green Island, Roxas (January 1, 2016; January 21, 2020 respectively); *Eucheuma denticulatum* cultivar "spinosum" from Honda Bay, Puerto Princesa, and

Panindigan, San Vicente (16 June 2014; January 21, 2020, respectively) (Figure 2).

Control cultivars were used in Green Island, Roxas, and Amogues, Taytay, Palawan. These control cultivars refer to the types of *Kappaphycus* and *Eucheuma* being farmed at the planting sites during the course of the study. Particularly the *K. alvarezii* cultivar "cottonii" served as the control cultivar for "tambalang" and "lakatan" while the *K. striatus* cultivar "bukoy" and *E. denticulatum* cultivar "butay" for "sacol" green and "magnolia" and "spinosum'' brown, respectively (Figure 3). Table 1 presents the summary of field-testing experiment conducted in Green Island, Roxas and Amogues, Taytay, Palawan.

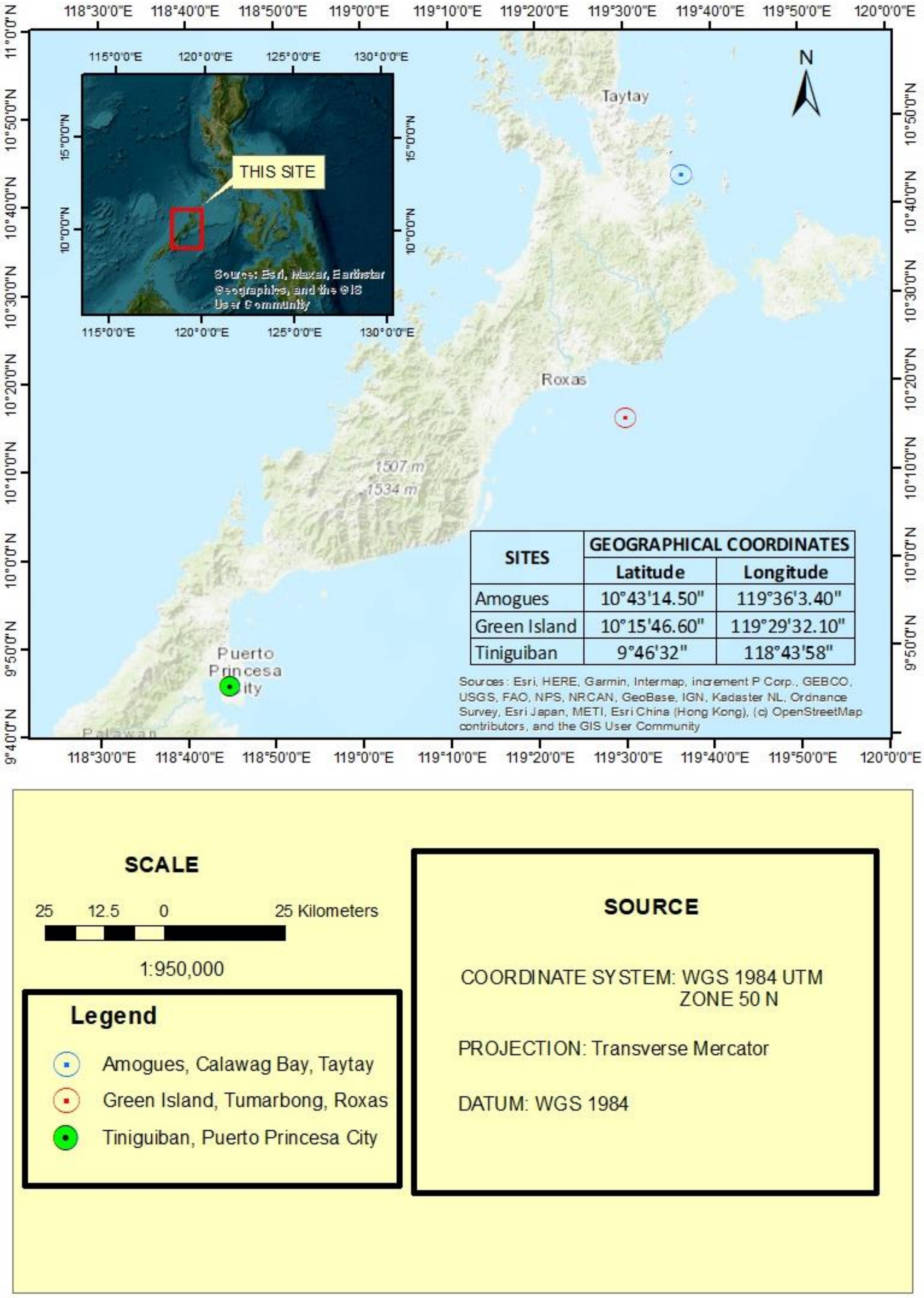

Figure 1. Map of the study sites in Palawan. The inset indicates the location of Palawan within the Philippines.

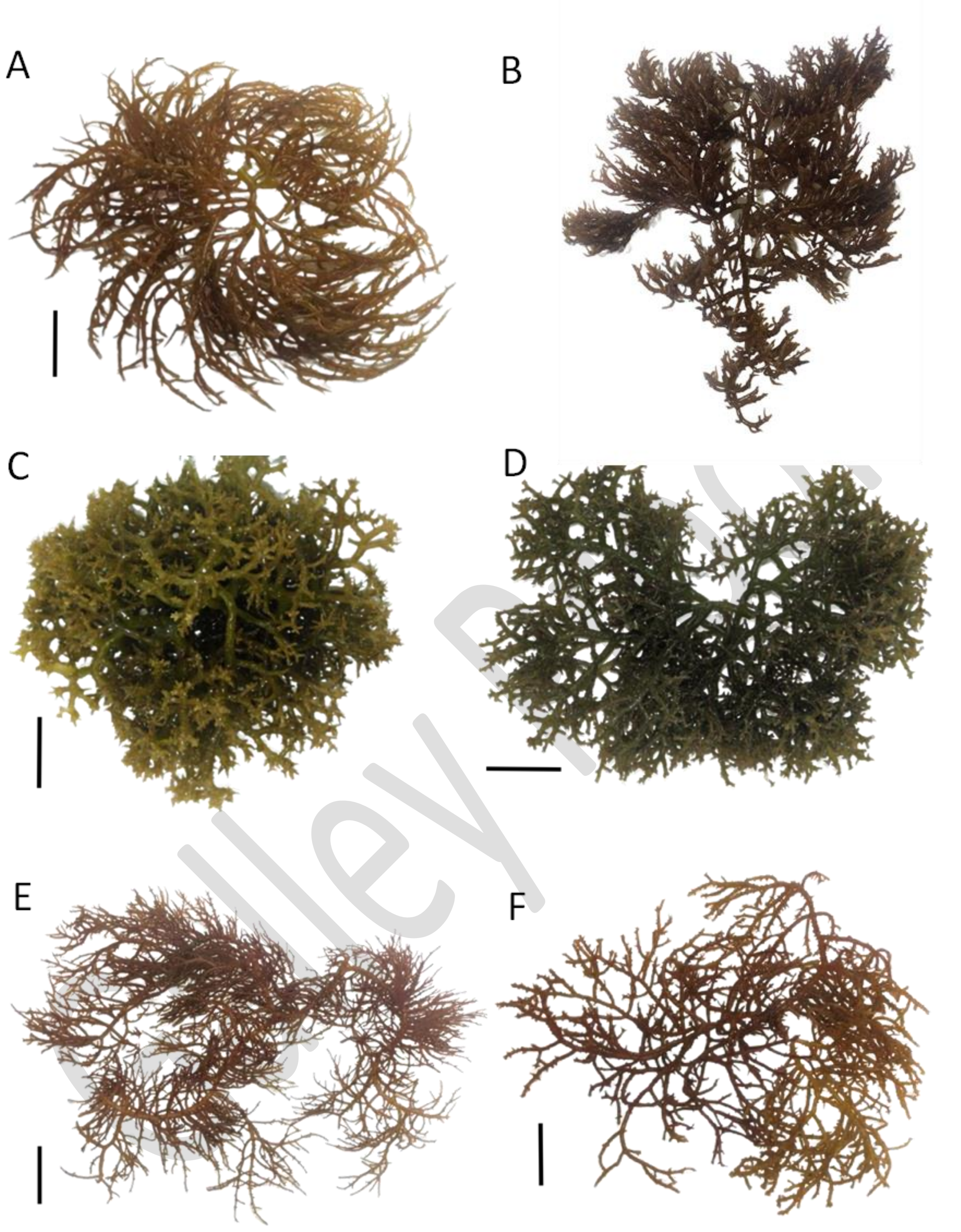

Figure 2. Seaweed cultivars used in this study “tambalang” (A); “lakatan” (B); “sacol” green (C); “magnolia” (D); “spinosum” brown from Honda Bay, Puerto Princesa; (E) and “spinosum” brown from San Vicente Palawan (F). Scale bar length: 7 cm.

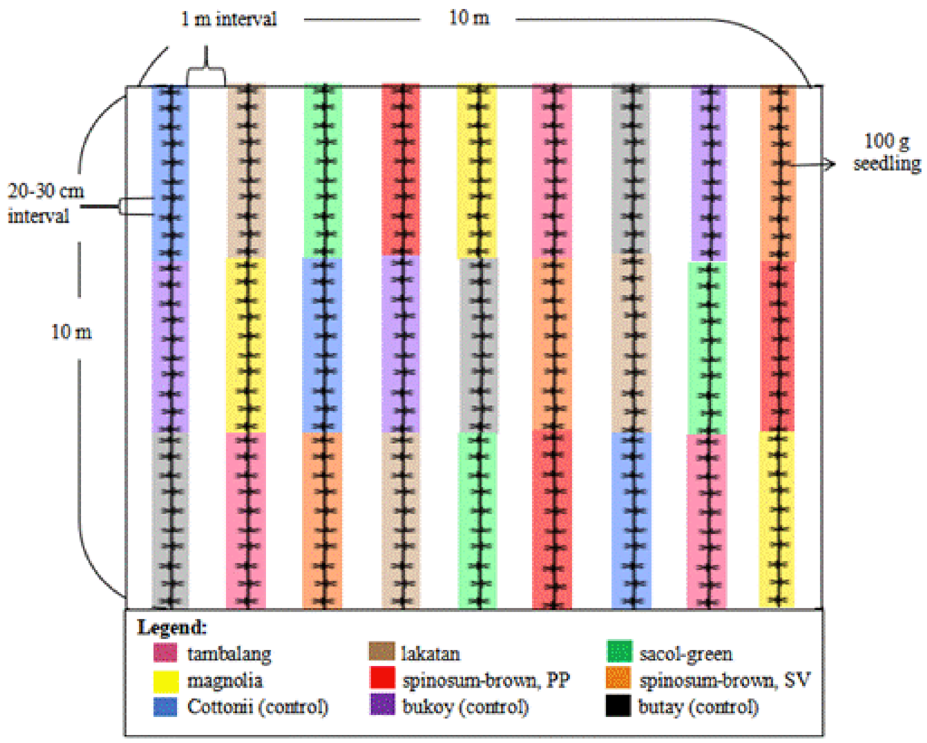

Figure 3. Experimental lay-out of the field-tested cultivars at Green Island and Sitio Amogues in the municipalities of Roxas and Taytay, Palawan.

Table 1. Summary of field-testing experiment conducted in Green Island, Roxas and Amogues, Taytay, Palawan.

Sites	Activities	Cultivars		Duration of Culture	Number of Cropping Cycles	
		Field-tested	Control		Wet Season	Dry Season
Tiniguiban, Puerto Princesa City	Mass propagation of seedlings	tambalang lakatan sacol-green magnolia spinosum- brown PP spinosum-brown SV	None	July 24, 2017 to June 29, 2021 July 24, 2020 to June 29, 2021 July 24, 2017 to June 29, 2021 February 27, 2020 to June 29, 2021 March 27, 2020 to June 29,2021 January 2021-June 29, 2021	Not recorded	Not recorded
Green Island, Roxas, Palawan	Field-testing of the six cultivars	tambalang lakatan sacol-green	cottonii cottonii bukoy	July 1, 2021 to June 30, 2022	5	3
Sitio Amogues, Taytay, Palawan	Field-testing of the six cultivars	magnolia spinosum- brown PP spinosum-brown SV	bukoy butay butay	August 16, 2021 to August 15, 2022	5	3

Measurement of Cultivars' Daily Growth Rates

The daily growth rates of at least 10 individual thalli per cultivar were measured at 15-day intervals per 45-days cropping cycle, covering the months of July 1 to December 30, 2021 and July 1 to August 15, 2022 for the wet season (225 days) and February 16 to June 30, 2022 for the dry season (135 days). The DGRs per cropping cycle represent the average DGR of the three measurements done (every 15^{th}, 30^{th}, and 45^{th} day of cultivation). The computed DGRs were compared among cultivars, between planting sites, and across planting seasons. The % DGRs was computed using the formula recommended by Yong et al. (2013):

$$DGR\ (\%) = \left[\left(\frac{W_t}{W_0}\right) \times \frac{1}{t-1}\right] \times 100$$

where W_t is the final weight, W_o is the initial weight, and t refers to days of culture.

A cropping calendar was developed, indicating the viable cultivars for cultivation on farms. This included cultivars with DGRs higher than those of the control cultivars.

Statistical Analysis

Descriptive statistics (i.e., averages and ranks) were employed to summarize the data. Statistical analyses were performed using RStudio software version 2021.09.0 (R Core Team 2018). All statistical testing was performed at $\alpha = 0.05$. The assumption of normality was confirmed by the Shapiro-Wilk test. To determine the differences in the average DGRs among cultivars and species, the one-way ANOVA and the Tukey-Kramer (post-hoc) test were implemented. The T-test for independent samples was performed to test whether the average DGRs of cultivars differ significantly between planting sites and seasons.

RESULTS

Cultivars' Daily Growth Rates

The mean daily growth rates of the six cultivars in two planting sites over eight cropping cycles (360 days) are presented in Figure 4. Among these cultivars, "spinosum" brown from Puerto Princesa and "sacol" green had the highest mean DGRs, 4.28% and 4.10%, respectively. The "spinosum" brown from San Vicente followed with a mean DGR of 3.65%, then the "lakatan" (3.55%), and "magnolia" (3.26%). The "tambalang" obtained the lowest mean DGR with only 3.24%. A comparison of mean DGRs among cultivars ($p < 0.001$) and species ($p = 0.008$) revealed significant differences at alpha 0.05 , or significance level. Post-hoc results suggested that the mean DRG of "spinosum"- brown from Puerto Princesa was significantly higher than than that of "spinosum"-brown from San Vicente. Similarly, the mean DGR of "sacol"-green was significantly higher than that of "magnolia," while "tambalang" and "lakatan" DGRs did not vary significantly with each other. Consequently, the cultivars of the species *Eucheuma denticulam* had significantly higher DGR compared to the cultivars of *Kappaphycus striatus* and the cultivars of *Kappaphycus alvarezii*. Between the *K. striatus* and *K. alvarezii*, the former had significantly higher DGR than that of the later.

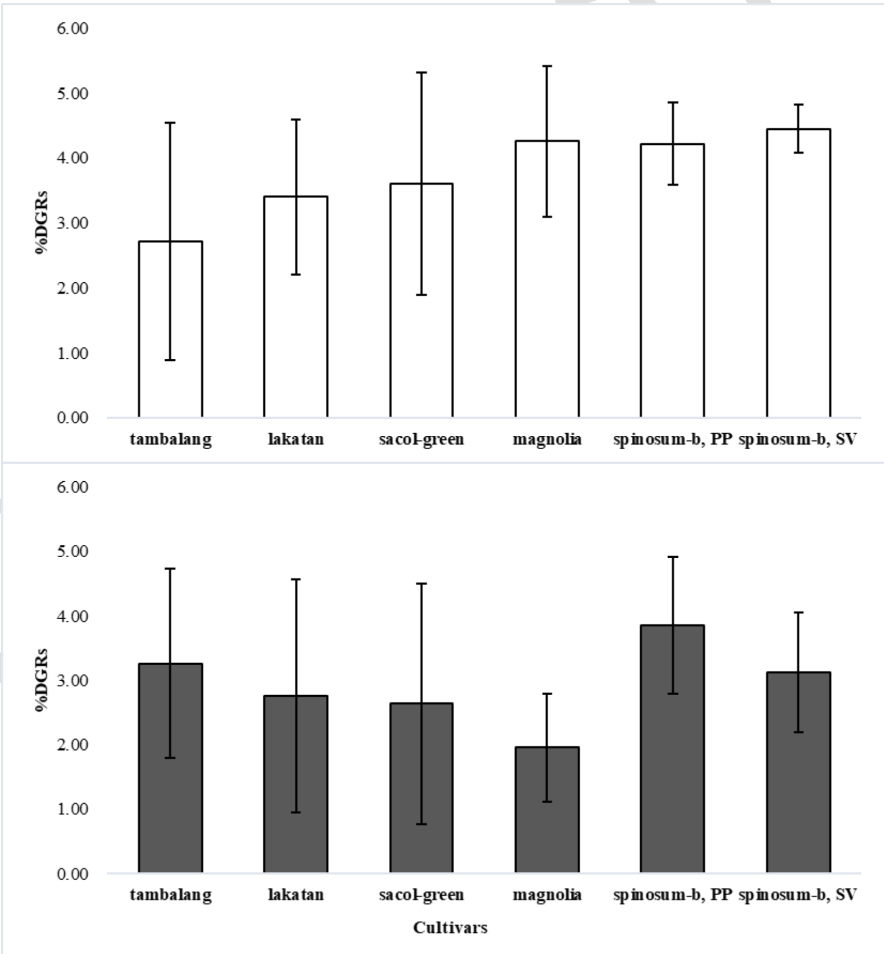

Figure 4. Comparative mean percent daily growth rates of the six field-tested cultivars in Green Island, Roxas (top) and Amogues, Taytay (bottom), Palawan. Bar lines indicate the standard deviations.

Spatial and Seasonal Variations in Cultivars' Daily Growth Rates

The DGRs of cultivars in two planting sites, Green Island, Roxas, and Amogues, Taytay, in Palawan, are presented in Figure 5. Four cultivars obtained significantly different DGRs between planting sites. The "tambalang" ($p = 0.010$) and "magnolia" ($p = 0.006$) had DGRs of 3.26% and 4.08%, respectively, in Green Island, Roxas, while the "spinosum" brown from Puerto Princesa ($p < 0.001$) and San Vicente ($p < 0.001$) in Amogues, Taytay, had DGRs of 4.86% and 4.45%, accordingly. In particular, except for the "tambalang", all other cultivars planted in Green Island, Roxas had relatively higher DGRs than their respective control cultivars, the "cottonii" (2.84% DGR) for "lakatan and "bukoy" (1.73% DGR) for "sacol"- green and "magnolia"; and the "butay" (3.3% DGR) for "spinosum" brown PP, and "spinosum" brown SV. In Amogues, Taytay, the "lakatan" and "spinosum"- brown SV obtained a relatively lower DGRs than their respective control cultivars, the "cottonii" and "butay", respectively.

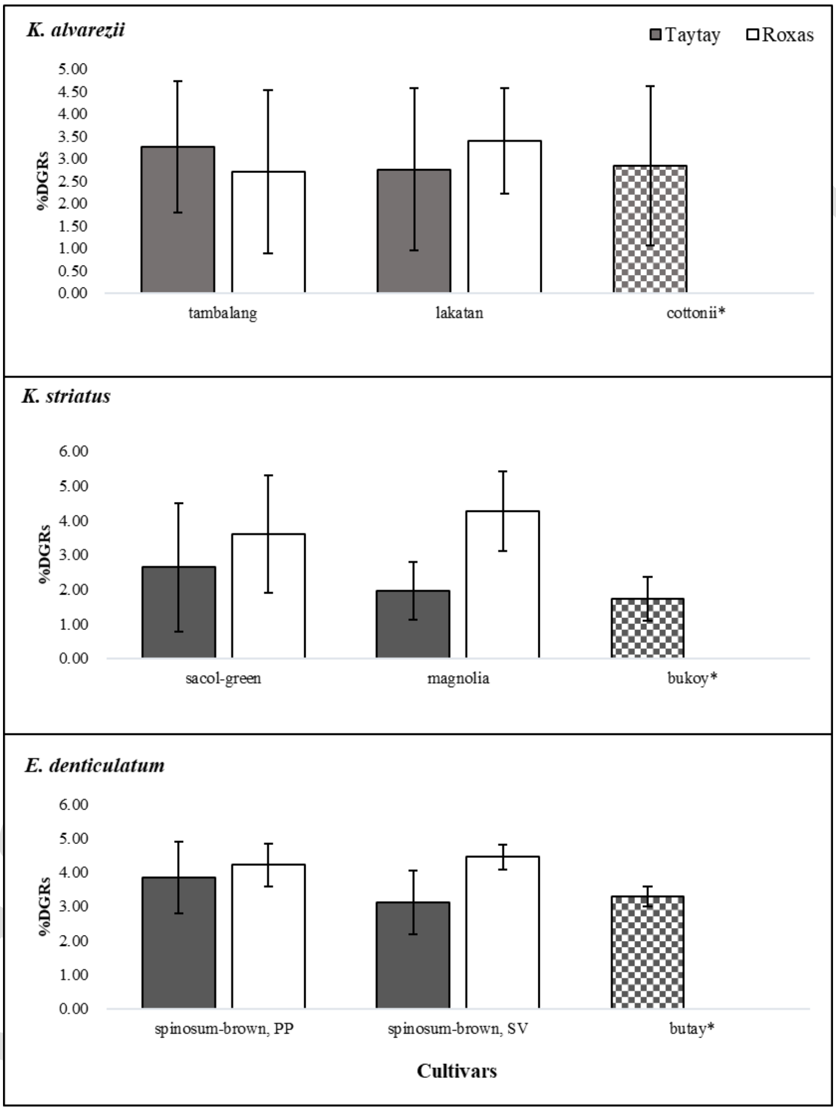

Figure 5. Comparative mean percent daily growth rates of field-tested and control cultivars (with asterisk) in Palawan with respect to planting sites. Bar line indicates the mean standard deviation.

A comparison of cultivar DGRs between seasons (wet and dry) in Green Island, Roxas, and Amogues, Taytay, is shown in Figure 6. Three cultivars grown from Green Island, Roxas, obtained significantly higher DGRs during the wet season. These were the "tambalang" ($p = 0.000$; 3.98% DGR), "magnolia ($p = 0.000$; 4.57% DGR), and "spinosum"-brown from Puerto Princesa ($p = 0.006$; 5.23% DGR). In Amogues, Taytay, all six cultivars obtained significantly higher DGRs during the wet season:

“tambalang” (*p = 0.210*; 3.17%DGR); “lakatan” (*p = 0.004*; 4.15%DGR); "sacol"-green (*p = 0.000*; 3.23%DGR); “magnolia” (*p = 0.004*; 2.69%DGR); “spinosum”- brown from Puerto Princesa (*p = 0.00*0; 3.97%DGR) and San Vicente (*p = 0.00*; 3.39%DGR). In general, the “lakatan”, “sacol”, and “magnolia” grew best during the months of July to December in Green Island, Roxas but only during the months of October to November in Amogues, Taytay. The two “spinosum” cultivars can be planted year-round in Green Island, Roxas, but in Amogues, Taytay, only during the months of August to December. The ideal season for “tambalang” planting in Green Island, Roxas, was from September to October, while in Amogues, Taytay, it is from October to November (Figure 7). Relative to the average DGRs of the control cultivars, a cropping calendar showing the recommended cultivars to be planted in the two sites at a particular cropping season is developed from this study (Figure 8).

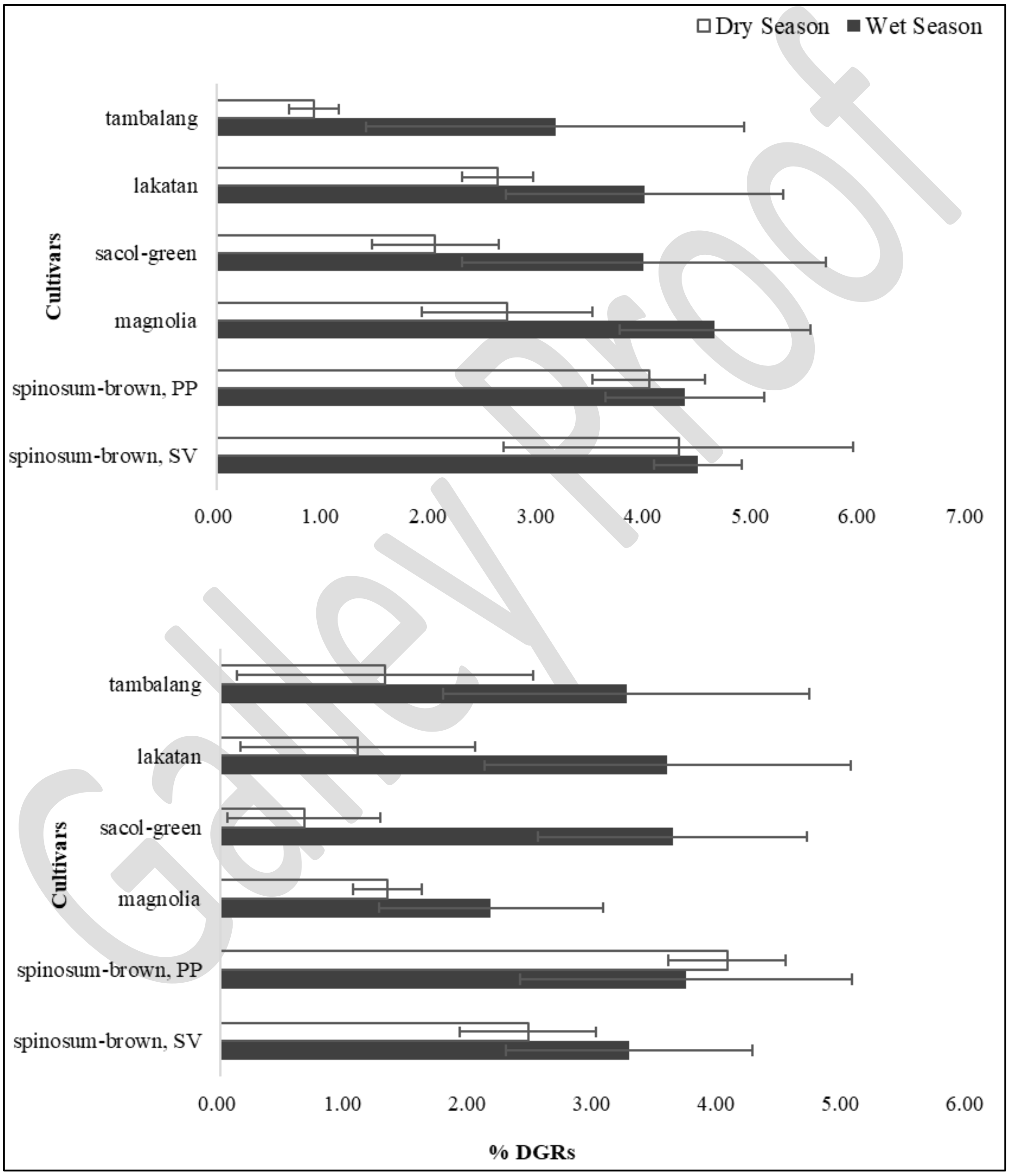

Figure 6. Comparative mean percent daily growth rate of seaweed cultivars in Green Island, Roxas (top) and Amogues, Taytay (bottom), Palawan with respect to cropping seasons (wet and dry). Bar line indicates the mean standard deviation.

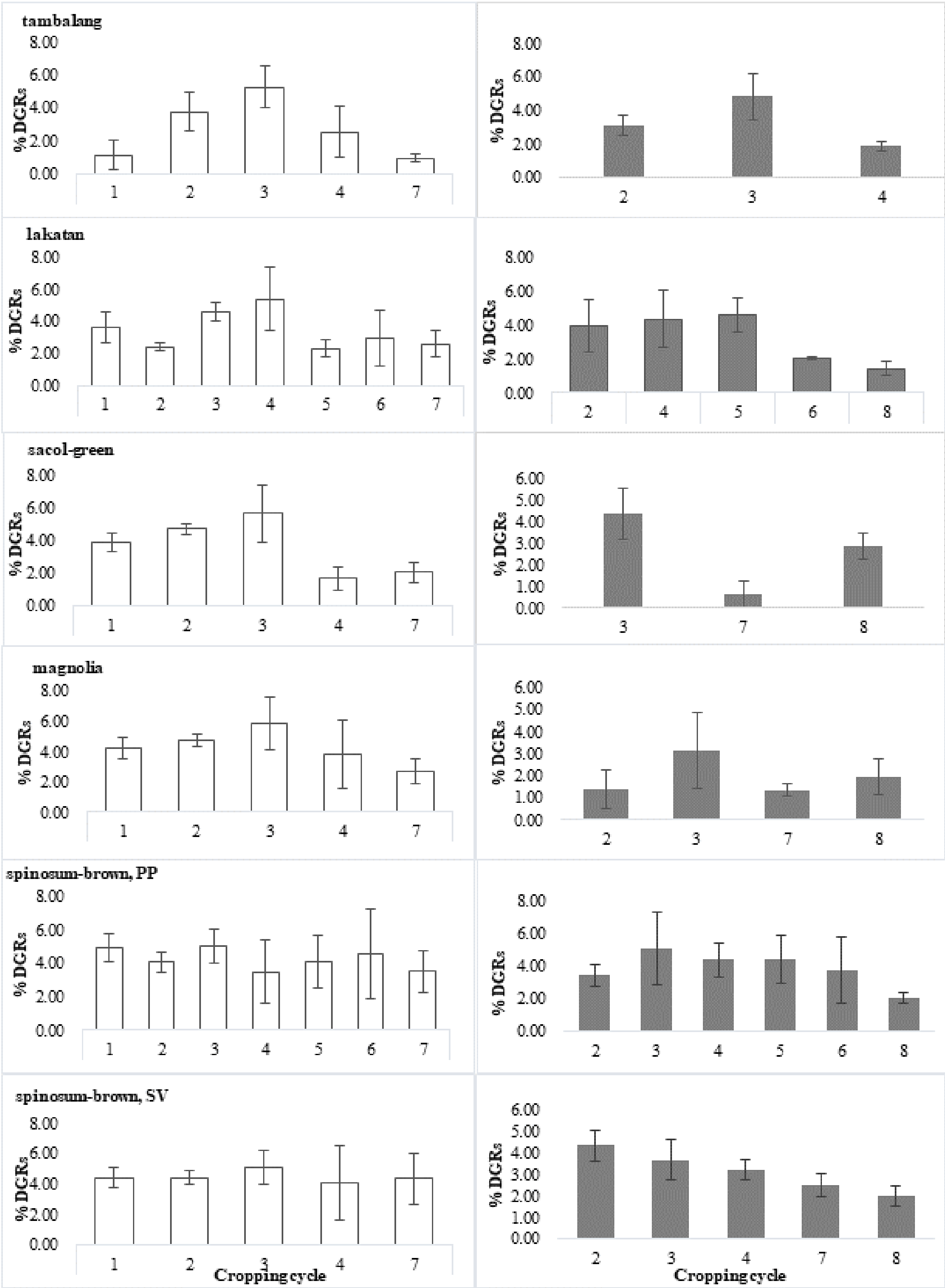

Figure 7. Comparative mean percent daily growth rate of seaweed cultivars in Green Island, Roxas (left) and Amogues, Taytay (right), Palawan with respect to cropping cycle (1 = July 1-Aug. 15, 2021; 2 = Aug. 16-Sept. 30, 2021; 3 = Oct. 1-Nov. 15, 2021; 4 = Nov. 16-Dec. 31, 2021; 5 = Feb. 16-March 31, 2022; 6 = April 1-May 15, 2022; 7 = May 16-June 30, 2022; 8 = July 1-Aug. 15, 2022). Bar line indicates the standard deviation.

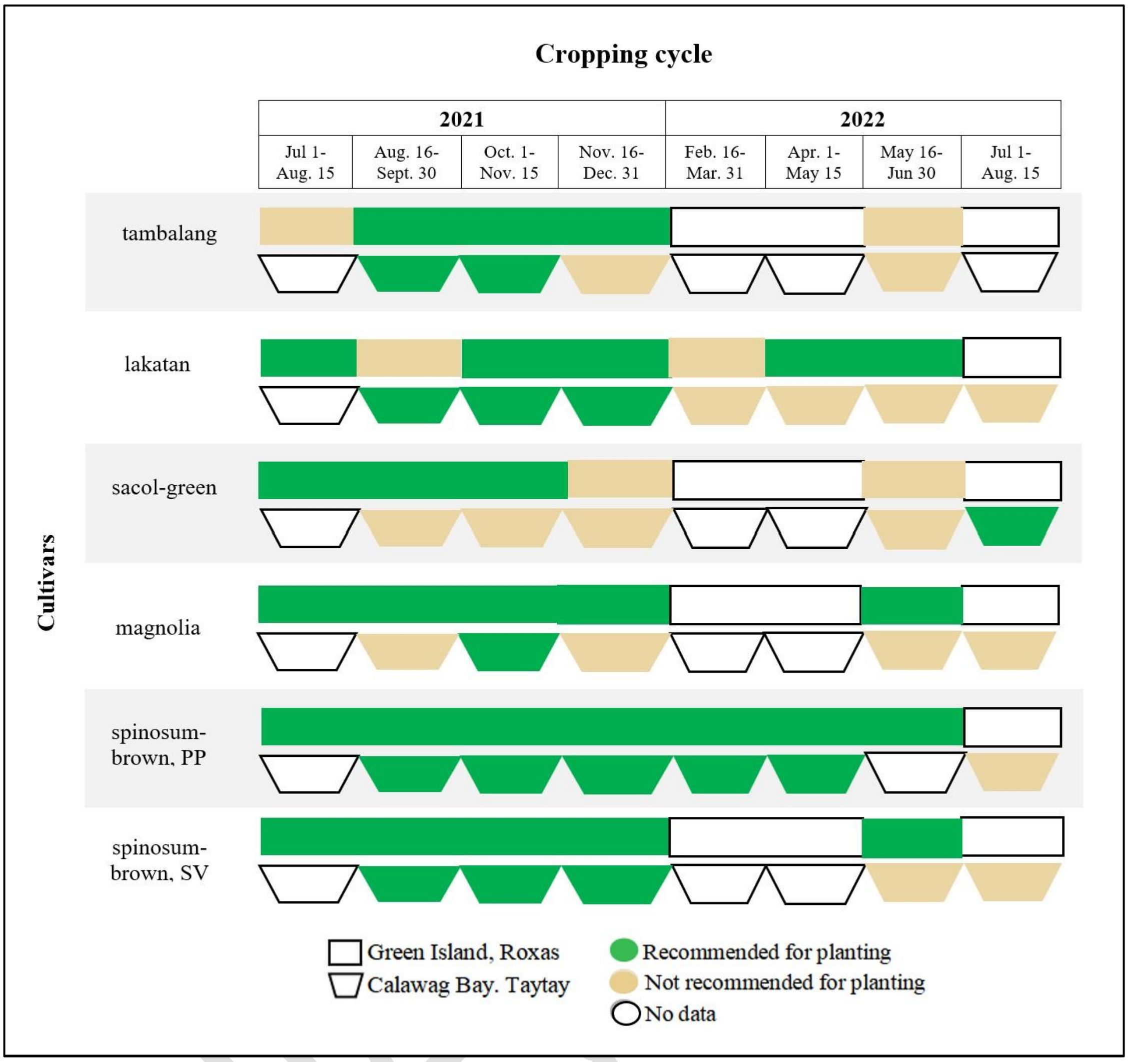

Figure 8. Cropping calendar recommended for seaweed cultivation in Palawan based from the selection dataset (average %DGRs) presented in this study.

DISCUSSION

Cultivars' Daily Growth Rates

The daily growth rates of cultivars differed among the three species. The *E. denticulatum*, had the highest growth rate compared to *K. alvarezii*, and *K. striatus*. In contrast, a similar study conducted in Bolinao, Pangasinan, revealed a higher DGR for *K. alvarezii*, 6.75% as opposed to only 5.06% for *E. denticulatum* (Dawes et al. 1994). The average DGR of *K. alvarezii* cultivars in this study, (3.39%) was relatively higher than those from Guimaras (2.06%) and Negros Oriental (2.44%) (Naguit et al. 2009), but lower than those from Pangasinan (6.75%) (Dawes et al. 1994); Zamboanga del Norte (3.52%) (Naguit et al. 2009); Zamboanga City (5.01%) (Hurtado et al. 2012); and Lanao del Norte (4.88%) (Orbita 2013). As observed in this study, cultivars of *K. alvarezii* were more vulnerable to ice-ice disease and changing environmental conditions (e.g., such as prolonged high sea surface temperatures and abrupt moderate to strong rainfall). This negative shift over the years in the growth performance among farmed eucheumatoids can be attributed to genetic instability and modifications due to the vegetative manner of propagating these seaweeds (Brakel et al. 2021). The repetitive use of the same old-age planting material can result in the production of an inferior line of propagules that are genetically inferior (Dumilag et al. 2003). The "cottonii" (*Kappaphycus*) propagules are highly preferred by farmers because of their higher market value, whether sold as fresh or raw dried seaweeds. The "spinosum" (*Eucheuma*), on the other hand, is less exploited for farming because of its lower market value and has retained its resistance to "ice-ice" disease, making it easier to propagate (De San 2012). The *Eucheuma denticulatum* produces volatile halocarbons (VHCs) when exposed to strong light and carbon dioxide-deficient environments (Mtolera et al. 1996). The VHCs act against microorganism infections, herbivore grazing, space competitors, and detrimental fouling by different kinds of epiphytes (Pang et al. 2015).

Spatial and Seasonal Variabilities in Cultivars' Daily Growth Rates

The cultivars daily growth rates differed significantly between planting sites. This variability can be attributed to the location of seaweed farms in Green Island, Roxas, and Amogues, Taytay. It appeared that farm sites nearshore-exposed (in Green Island, Roxas) are more ideal for farming than the nearshore-sheltered sites (in Amogues, Taytay). These marine environment categories, including offshore and reef-protected areas, were recognized to discriminate ideal seaweed farms. Seaweed farm productivity in nearshore-sheltered coastal areas of tropical countries is extremely affected by rising upper surface ocean temperatures and is more susceptible to slowing water movement and the spread of diseases and pests Tullberg et al. (2022).

The cultivars daily growth rates also varied across planting seasons. Higher growth rates of cultivars were attained during the rainy season, with optimum growth in October to November. During this period, the surface seawater was colder and more turbulent due to monsoon rains and winds. Such a condition, as previously reported, is ideal for seaweed growth (Azanza and Sa-a 1990; Orbita 2013; Simatupang et al. 2021). The lower growth rates during the dry season can be attributed to a warmer seawater surface temperature and the occurrence of ice-ice disease. This scenario was previously observed in the growth rates of *K. alvarezii* in Antique, Philippines (Hurtado et al. 2001) and Cam Ranh Bay, Vietnam (Hung et al. 2009) during the months of April and May. Several other factors such as water movement, salinity, dissolved oxygen, pH, and nutrient contents can likewise affect the growth performance of seaweed cultivars (Orbita 2013; Kasim et al. 2017; Perenrengi et al. 2020).

The daily growth rates can be one of the criteria for seaweed selection in farming. The selected fast-growing cultivars should be the ones recommended for mass cultivation on farms to increase farm yields. However, this is just one of the many approaches toward a sustainable seaweed farming operation in Palawan, or in the entirety of the country. Given the overall decreasing trend in cultivars' growth performance over the years due to the changing climate, urgent action to characterize the seaweed farms in the province is highly suggested. Deteriorating seawater quality caused by local stressors or threats (i.e., sewage input, use of commercial fertilizer in seaweed farming) might have a significant impact on seaweed productivity. Site exploration to locate wild populations of *Kappaphycus*, *Eucheuma*, and other carrageenan-bearing seaweeds are equally important. Cultivars from the wild that are not yet exploited in farming, are genetically more viable and are good candidates for strain selection experiments. Nevertheless, the selected fast-growing cultivars from this study can be used for future micropropagation, tissue culture, and hybridization studies to advance the selection and dispersal of quality seedlings to the farmers of Palawan.

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ETHICAL CONSIDERATION

There are no human or animal subjects in this article and informed consent is not applicable.

DECLARATION OF CONFLICTING INTEREST

No potential conflict of interest was reported by the authors.

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