

Morphological variation of two common sea grapes (*Caulerpa lentillifera* and *Caulerpa racemosa*) from selected regions in the Philippines

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Abstract. Estrada JL, Bautista NS, Dionisio-Sese ML. 2020. Morphological variation of two common sea grapes (*Caulerpa lentillifera* and *Caulerpa racemosa*) from selected regions in the Philippines. *Biodiversitas* 21: 1823-1832. Seagrapes, locally known in the Philippines as “lato” or “ar-arusip”, are economically important macroalgae belonging to the edible species of the genus *Caulerpa*. This study characterized and compared distinct populations of sea grapes from selected regions in the Philippines and described the influence of physicochemical parameters of seawater on their morphology. Morphometric, cluster and principal component analyses showed that morphological plasticity exists in sea grapes species (*Caulerpa lentillifera* and *Caulerpa racemosa*) found in different sites in the Philippines. These are evident in morphometric parameters namely, assimilator height, space between assimilators, ramulus diameter and number of rhizoids on stolon wherein significant differences were found. This evident morphological plasticity was analyzed in relation to physicochemical parameters of the seawater. Assimilator height of *C. racemosa* is significantly associated and highly influenced by water depth, salinity, temperature and dissolved oxygen whereas for *C. lentillifera* depth and salinity are the significant influencing factors. Highest assimilator height of sea grapes was found in Coron and Culion in Palawan due to higher salinity and temperature while in Mactan, Cebu, it is primarily attributed to lower depth and higher salinity values.

Keywords: *Caulerpa*, morphological variation, Philippines, plasticity, sea grapes

INTRODUCTION

Seagrapes are economically important macroalgal species of the genus *Caulerpa* (Caulerpaceae, Chlorophyta) utilized for local consumption and international trade in the Philippines and other Southeast Asian countries. Considered also as edible seaweeds (Pereira 2016; Dumilag 2019), sea grapes in the Philippines are collectively recognized into two species, *Caulerpa lentillifera* J. Agardh and *Caulerpa racemosa* (Forsskal) J. Agardh, which are mainly found in the wild or cultured in ponds. Locally known as “lato” or “ar-arusip”, both are seafood used in salads (Nguyen et al. 2011; Delan et al. 2013). Seagrapes contain high mineral content, protein, polyunsaturated fatty acids (PUFAs) and vitamins (Saito et al. 2010; Peña-Rodriguez et al. 2011; Nagappan and Vairappan 2014). At present, phycculture of sea grapes in the Philippines is primarily of *C. lentillifera*, which is also traded internationally from the Philippines into other Southeast Asian countries (Rabia 2016).

Seaweeds are known for their phenotypic plasticity; the same species of seaweeds can exhibit morphological variations under different environmental conditions. The green macroalgal genus *Caulerpa* J.V. Lamouroux, in which *C. lentillifera* and *C. racemosa* belong, exhibits high levels of phenotypic plasticity due to environmental factors

(Belton et al. 2014). There are currently ninety-seven (97) taxonomically recognized species associated with the genus (Guiry and Guiry 2019). The genus inhabits substrates from intertidal to subtidal zones, from reef flats to shallow muddy lagoons (Baleta and Nalleb 2016; Wichachucherd et al. 2019) and is primarily distinguished by having a siphonous thallus differentiating into stolons, rhizoids, and upright assimilators (or fronds) that usually bear ramuli (or branchlets). These morphological structures have been used for species characterization and delimitation, although have been found to exhibit environmentally controlled morphological plasticity under changing environmental conditions (Belton et al. 2014; Riosmeña-Rodriguez et al. 2014).

This study investigated the morphological variations of sea grapes from various regions in the Philippines as influenced by physicochemical parameters of the seawater using morphometric, cluster and principal component analyses. Understanding the morphological plasticity of sea grapes can provide insights regarding the physiological mechanisms of acclimatization necessary to persist and adapt to environmental changes in order to increase resource availability and enhance biomass productivity. Data can also be used by fisherfolks and sea grape farmers as basis in choosing suitable areas for sustainable phycculture and wild harvesting of sea grapes.

MATERIALS AND METHODS

Study areas

The algal specimens were collected from thirteen (13) different municipalities in five (5) regions in the Philippines within three (3) geographical locations, namely: Pagudpud and Burgos, Ilocos Norte and Agno, Pangasinan (Region 1) in Northern Luzon; Calatagan in Batangas (Region 4A), Calapan and Puerto Galera in Oriental Mindoro, Tablas Island in Romblon, and Coron and Culion, Palawan (Region 4B) all in Southern Luzon; and Estancia and San Joaquin in Iloilo (Region 6), and Mactan and Camotes Islands in Cebu (Region 7) in the Visayas (Table 1, Figure 1). The localities were selected as

sites for specimen collection due to the presence of wild harvesting and phyoculture of sea grapes (Trono 1997).

Collection and identification of sea grapes

Seagrapes specimens were obtained from intertidal and shallow subtidal regions in the different sampling areas by snorkeling or wading. A total of fifty-seven (57) biological samples inclusive of replicates were collected and analyzed in this study. Morphology-based examination and identification *in situ* were mainly based on Trono (1997, 2004) and Verlaque et al. (2000). Algaebase (Guiry and Guiry 2019), an international database for algal taxonomy was also used to reference the species names.

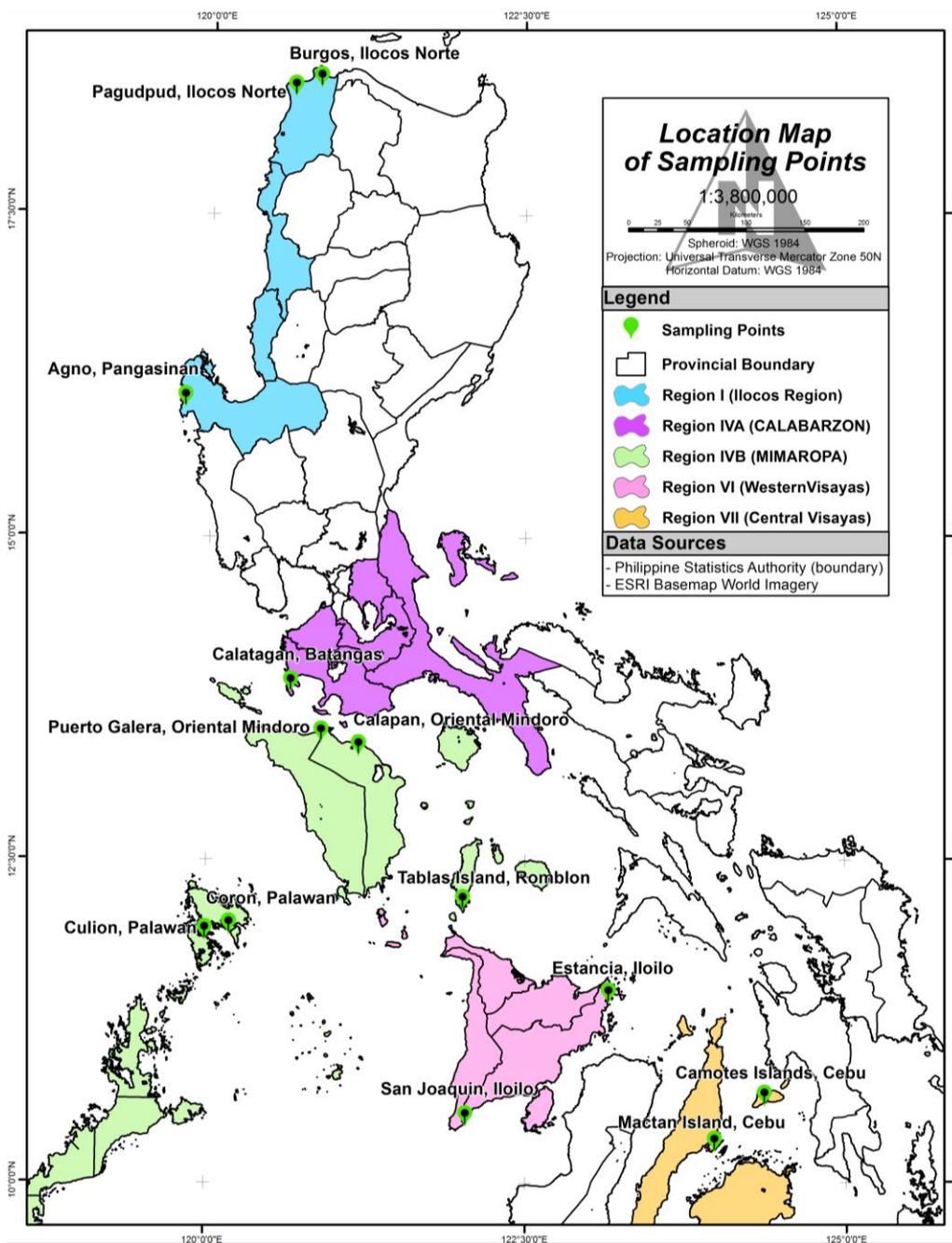


Figure 1. Map of the Philippines indicating the sampling sites of sea grapes collection (generated using ArcGIS 10.4).

Table 1. List of thirteen (13) sites for sea grapes collection in the Philippines and their respective coordinates

Site no.	Collection Sites	Coordinates
1	Brgy. Quilitisan, Calatagan, Batangas	13°52'40" N 120°36'48" E
2	Brgy. Paayas, Burgos, Ilocos Norte	18°29'59" N 120°34'6" E
3	Brgy. Caparispisan, Pagudpud, Ilocos Norte	18°35'50" N 120°46'56" E
4	Brgy. Aloleng, Agno, Pangasinan	16°6'18" N 119°45'40" E
5	Guinpasilan Islet, Agojo, Looc, Tablas Island, Romblon	12°12'2" N 121°58'38" E
6	Brgy. Camao, San Francisco, Camotes Islands, Cebu	10°38'3" N 124°23'21" E
7	Brgy. Kalawisan, Lapu-Lapu, Mactan Island, Cebu	10°17'1" N 123°56'3" E
8	Brgy. Sinogbuan, San Joaquin, Iloilo	10°28'44" N 122°27" E
9	Brgy. Daculan, Estancia, Iloilo	11°28'40" N 123°9'48" E
10	Brgy. Salong, Calapan, Oriental Mindoro	13°25'18" N 121°11'13" E
11	Sitio Maniknik, Brgy. Balatero, Puerto Galera, Oriental Mindoro	13°30'33" N 120°56'8" E
12	Sitio Look, Brgy. Lajala, Coron, Palawan	11°58'47" N 120°10'33" E
13	Chindonan Island, Brgy. Libis, Culion, Palawan	11°55'54" N 120°37" E

Morphological characterization

Three replicates of the sea grape samples per site were morphologically characterized *in-situ*. Morphometric measurements recorded for assimilators or upright fronds were: height, width, spacing, and numbers per stolon (2 cm); for branchlets: ramuli diameter, stalk length and stalk diameter; and for rhizoids: stolon diameter, rhizoid length and number of rhizoids per stolon (2 cm) (Figure 2). Assimilators consist of branchlets called ramuli which resemble “grapes” and are the edible parts of the species. Branching horizontal stolon gives rise to numerous assimilators and rhizoids at its ventral side for attachment. The protocol used for morphometric analysis in the study was described by Manas et al. (2015).

Measurement of physicochemical parameters of the seawater

Physico-chemical parameters were measured in the sites where sea grape samples were collected. These include depth, temperature, total suspended solids, turbidity, pH, electrical conductivity, dissolved oxygen and salinity. Electrical conductivity, surface water temperature and pH were determined using a Horiba U-10 Water Quality Checker (CA, USA) while salinity was measured using an ATAGO refractometer. Dissolved oxygen was measured using a Dissolved Oxygen meter. A Secchi disk was used to measure the depth from the surface water to the substratum of sampling zones. At each sampling point, 4-liter of water was taken using sampling bottles for the turbidity and total suspended solids analyses. Turbidity and total suspended solids were quantitatively measured *ex-situ* using Merck-SQ and Gravimetric-SMEWW methods. Other physical factors like weather conditions (temperature and rainfall) were noted during sampling. The measurement of each of the variables was conducted from March to May 2019 (peak season) and mostly in the morning between 07.00 to 12.00.

Data analysis

All data were analyzed first for normality and heteroskedasticity of variances using Shapiro-Wilk test and Breusch-Pagan/Cook-Weisberg test to comply with the assumptions of analysis of variance (ANOVA). The Dunn-

Bonferroni post-hoc test was done to determine significant differences among ranks. Analysis of variance (ANOVA) and Kruskal-Wallis test was used to test for significant differences ($p < 0.05$) of morphometric data of *C. lentillifera* and *C. racemosa* across different sites. Cluster analysis and principal component analysis were used to show similarities and differences of the sea grapes (*C. lentillifera* and *C. racemosa*) based on morphological markers and physicochemical parameters of their habitats from different localities using Unweighted Pair Group Arithmetic Mean (UPGMA) clustering method via Sequential Agglomerative Hierarchical and Non-overlapping (SAHN) Combinatory Strategy module in the Numerical Taxonomy and Multivariate Analysis System (NTSYS-pc) ver 2.10 by Applied Biostatistics Inc. (Rohlf 2002). Similarity coefficients for quantitative traits using Euclidean Distance Coefficient were used. The PAST (PAleontological STatistical) software version 3 and XLSTAT statistical software were used for these analyses. Pearson correlation analysis and multiple linear regression analysis were used to measure direction and strength of relationships between the morphometric data of *C. lentillifera* and *C. racemosa* and the physicochemical parameters of the seawater.

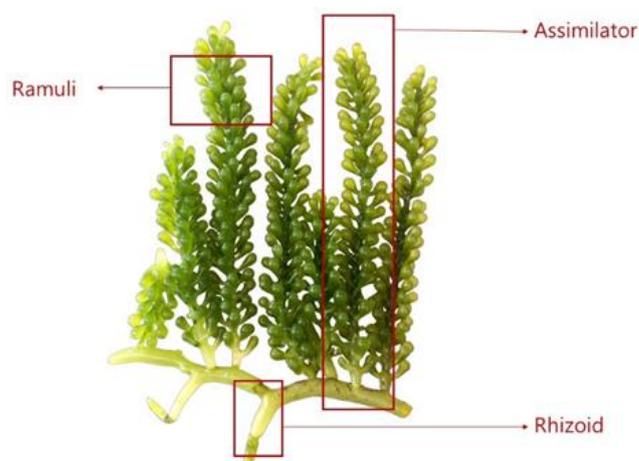


Figure 2. Morphometric parameters measured for assimilators, ramuli and rhizoids described by Manas et al. (2015)

RESULTS AND DISCUSSION

Identification of sea grapes

A total of two species and two varieties of sea grapes were identified from the entire collection, namely: *Caulerpa lentillifera* J. Agardh and *Caulerpa racemosa* (Forsskal) J. Agardh, the latter with varieties *turbinata* and *laetevirens* (Verlaque et al. 2000). However, *C. racemosa* var. *turbinata* (J. Agardh) Eubank and *C. racemosa* var. *laetevirens* (Montagne) Weber-van Bosse were regarded as synonyms of *C. chemnitzia* var. *turbinata* (J. Agardh) Eubank and *C. chemnitzia* var. *laetevirens* (Montagne) Weber-van Bosse, respectively, according to AlgaeBase (Guiry and Guiry 2019). Since species identification was done in this study was based only on morphological description and not on molecular identification, which was the major criterion in AlgaeBase, the two varieties were retained under *C. racemosa* in the succeeding analyses and discussion.

C. lentillifera is characterized as having ramuli with globose tips, which are constricted at the base and arranged imbricately in rows of four (Figure 3.A-B) while *C. racemosa* is characterized as having highly variable ramuli, which can be stipitate or substipitate and can be arranged irregularly - distichously, multiserially or imbricately (Figure 3.C-D). On the other hand, *C. racemosa* var. *turbinata* is characterized as having uncrowded ramuli which are clavate with flattened ends (Figure 3.E-F) while *C. racemosa* var. *laetevirens* have crowded ramuli which are cylindrical to gradually clavate (Figure 3.G-H). The sampling sites where these species were collected are summarized in Table 2.

Morphometric analysis

Caulerpa lentillifera

Table 3 shows the significant morphological differences in assimilators, branchlets and rhizoids found between populations of *C. lentillifera* across different sites in the Philippines. *C. lentillifera* from Coron, Palawan exhibited the highest assimilator height ranging from 110 to 130 mm but is not significantly different from the ones collected in Mactan, Cebu, which ranged from 100 to 110 mm. The *C. lentillifera* collections, however, from the other sites were significantly different from one another and from the samples collected from Coron, Palawan and Mactan, Cebu with the samples from Camotes Islands in Cebu showing the lowest assimilator height of 30-40 mm. In terms of assimilator width, *C. lentillifera* from Coron, Palawan again exhibited the highest assimilator width among the collected samples followed by Mactan, Cebu while samples from Camotes, Estancia and Tablas exhibited the lowest assimilator widths. Similarly, *C. lentillifera* assimilator represented in terms of number of assimilators on stolon is highest in Coron, Palawan. In terms of the spacing between assimilators, Camotes in Cebu had the lowest values among the collected samples. *C. lentillifera* from Coron, Palawan exhibited the highest ramulus diameter and stalk length followed by Mactan, Cebu (in stalk length) while samples from Camotes, Estancia, and Tablas were found similar to one another. With reference to stalk diameter, all the collected samples have no significant differences. No significant morphological differences in rhizoids characters (stolon diameter, rhizoid length and number of rhizoids on stolon) are also found between populations of *C. lentillifera* across different sites in the Philippines.

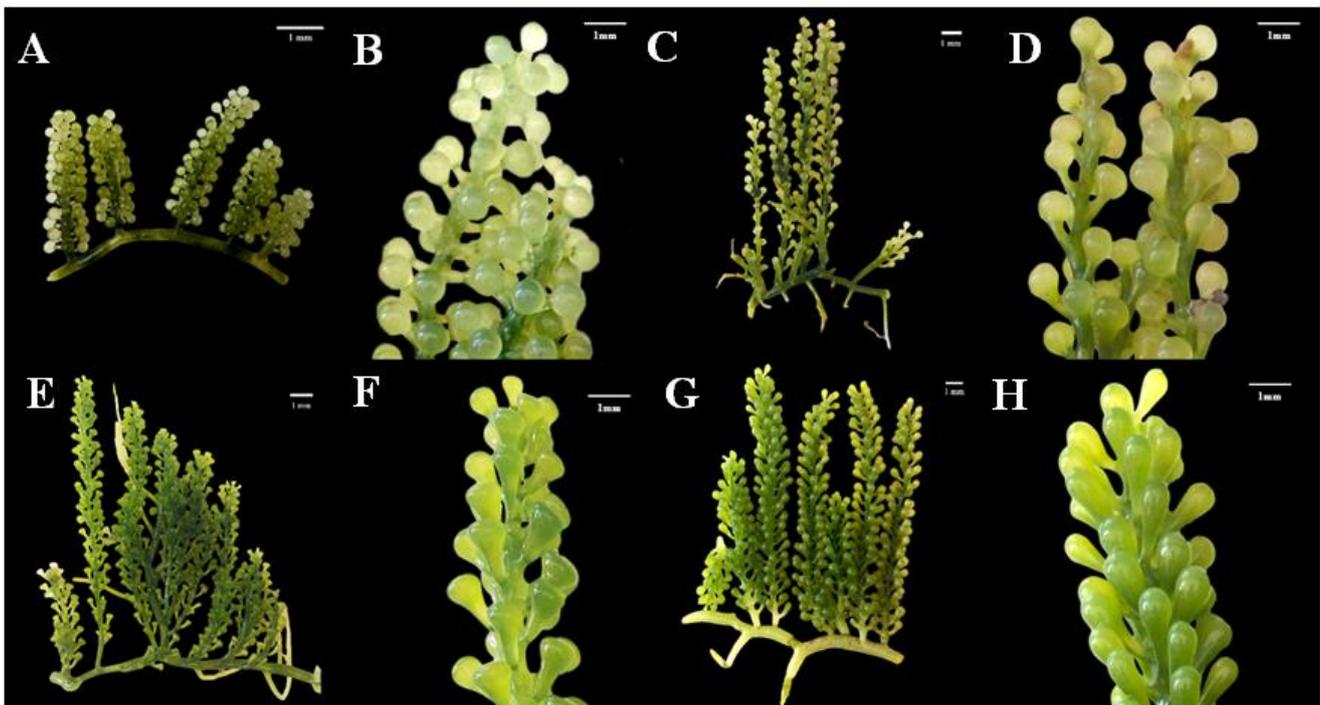


Figure 3. Identified sea grape species and varieties: (A-B) *Caulerpa lentillifera* and detailed part of assimilator, (C-D) *Caulerpa racemosa* and detailed part of assimilator, (E-F) *Caulerpa racemosa* var. *turbinata* and detailed part of assimilator, and (G-H) *Caulerpa racemosa* var. *laetevirens* and detailed part of assimilator. Scale bar = 1mm

Table 2. List of identified species of sea grapes and their distribution in the study. Species identification was mainly based on Trono (1997, 2004) and Verlaque et al. (2000)

Island	Region	Province	Town/Island	<i>C. racemosa</i> observed	<i>C. lentillifera</i> observed
Luzon	I	Ilocos Norte	Burgos	<i>C. racemosa</i>	
			Pagudpud	<i>C. racemosa</i>	
		Pangasinan	Agno	<i>C. racemosa</i>	
	IVA	Batangas	Calatagan	<i>C. racemosa</i>	
			Calapan	<i>C. racemosa</i>	
	IVB	Oriental Mindoro	Puerto Galera	<i>C. racemosa</i>	
			Coron	<i>C. racemosa</i> , var. <i>turbinata</i> var. <i>laetevirens</i>	<i>C. lentillifera</i>
		Palawan	Culion	<i>C. racemosa</i> , var. <i>turbinata</i> var. <i>laetevirens</i>	
Romblon	Tablas		<i>C. lentillifera</i>		
Visayas	VI	Iloilo	San Joaquin	<i>C. racemosa</i>	
			Estancia	<i>C. racemosa</i>	<i>C. lentillifera</i>
	VII	Cebu	Camotes	<i>C. racemosa</i>	<i>C. lentillifera</i>
			Mactan		<i>C. lentillifera</i>

Cluster analysis revealed that *C. lentillifera* samples from Camotes, Cebu were substantially different from all the other samples (Figure 4A). This is highly attributed to the lower values of morphometric measurements of samples from Camotes compared to the other sites. Furthermore, morphometric measurements revealed similarities between *C. lentillifera* samples collected in Coron and Mactan as well as those from Estancia and Tablas resulting in two clusters. Principal component analysis, on the other hand, showed that *C. lentillifera* samples from Mactan, Cebu, and Coron, Palawan have higher values in terms of morphometric parameters, namely assimilator height, assimilator width, number of assimilators on stolon, ramulus diameter, stalk length, stalk diameter, stolon diameter and number of rhizoids per stolon (Figure 4B). This indicates that samples from these two provinces are substantially different from the other sites due to bigger sizes. However, in terms of rhizoid length, all the samples collected were found to be similar. In contrast, *C. lentillifera* from the other sites (Camotes, Estancia and Tablas) have higher values in terms of spacing between assimilators and are therefore differentiated and grouped separately from the Coron and Mactan samples.

Caulerpa racemosa

Significant morphological differences in assimilators, branchlets and rhizoid characters were found between populations of *C. racemosa* across different sites in the Philippines (Table 4). In the present study, *C. racemosa* var. *laetevirens* (Coron 3), which was collected from Coron, Palawan, exhibited the highest assimilator height ranging from 160 to 190 mm and is significantly different from all the *C. racemosa* samples collected in other sites.

In terms of assimilator width, *C. racemosa* var. *laetevirens* also from Coron (Coron 3) exhibited the highest assimilator width among the collected samples. Samples of the same variety from Culion, Palawan (Culion 2) followed in rank. In contrast, *C. racemosa* from Burgos in Ilocos Norte and Camotes in Cebu exhibited the shortest assimilator widths among all the collected specimens. In terms of spacing between assimilators, *C. racemosa* var. *laetevirens* from Coron (Coron 3) and Culion (Culion 2) in Palawan exhibited the highest spacing whereas *C. racemosa* from Burgos and Pagudpud in Ilocos Norte exhibited the lowest. For the number of assimilators arranged on stolon, *C. racemosa* var. *turbinata* from Coron (Coron 2) and Culion (Culion 1) in Palawan exhibited the highest numbers whereas *C. racemosa* var. *laetevirens* from Coron (Coron 3) and Culion (Culion 2) in Palawan showed the lowest.

C. racemosa var. *turbinata* (Coron 2; Culion 1) and *C. racemosa* var. *laetevirens* (Coron 3; Culion 2) from Palawan exhibited the highest ramulus diameters while *C. racemosa* from Burgos and Pagudpud in Ilocos Norte as well as those collected in Camotes in Cebu exhibited the lowest diameters. In terms of stalk length and stalk diameter, *C. racemosa* var. *turbinata* (Coron 2 and Culion 1) from Palawan exhibited the highest stalk length while *C. racemosa* from Burgos and Pagudpud in Ilocos Norte exhibited the shortest stalk length and diameter among the collected samples. *C. racemosa* var. *laetevirens* from Coron, Palawan (Coron 3) exhibited the highest stolon diameter and is substantially different from the other samples. In terms of rhizoid length and number of rhizoids on stolon, *C. racemosa* from Camotes Islands in Cebu is different from the other collected samples, exhibiting the shortest rhizoid length and the highest number of rhizoids on stolon.

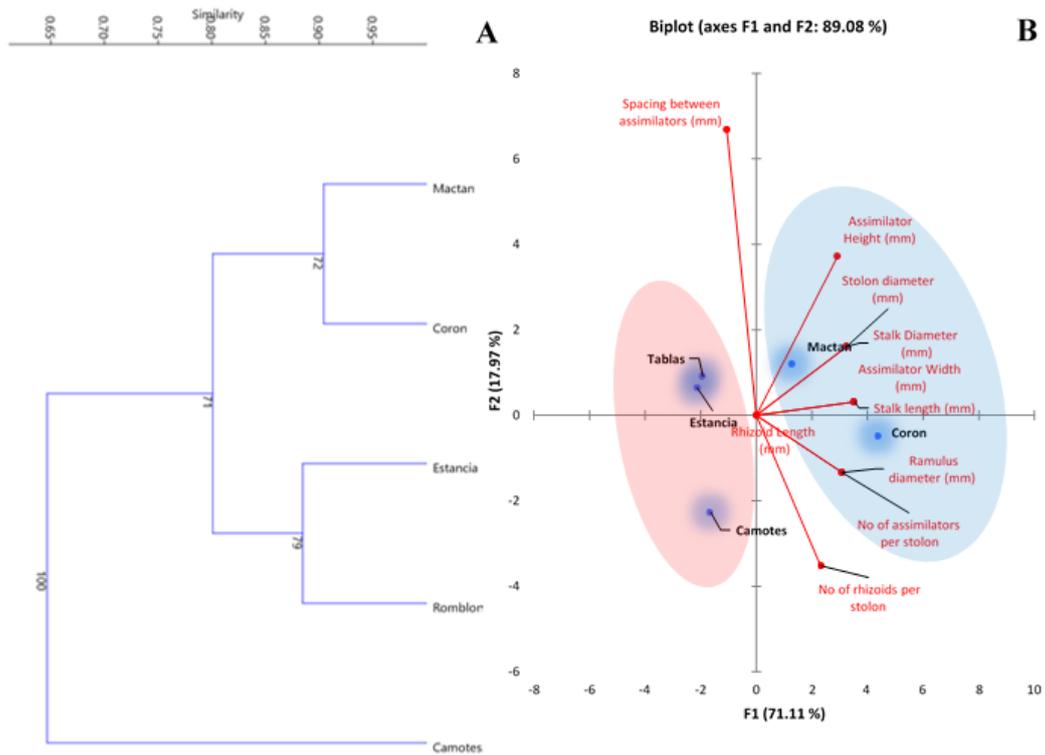


Figure 4. A. Cluster analysis showing the morphological similarities of *C. lentillifera* across different sites in the Philippines [PAST v3, Euclidean Similarity Index and Paired group (UPGMA)], and B. Principal component analysis showing relationship of morphometric variables to *C. lentillifera* samples across different sites in the Philippines (XLSTAT)

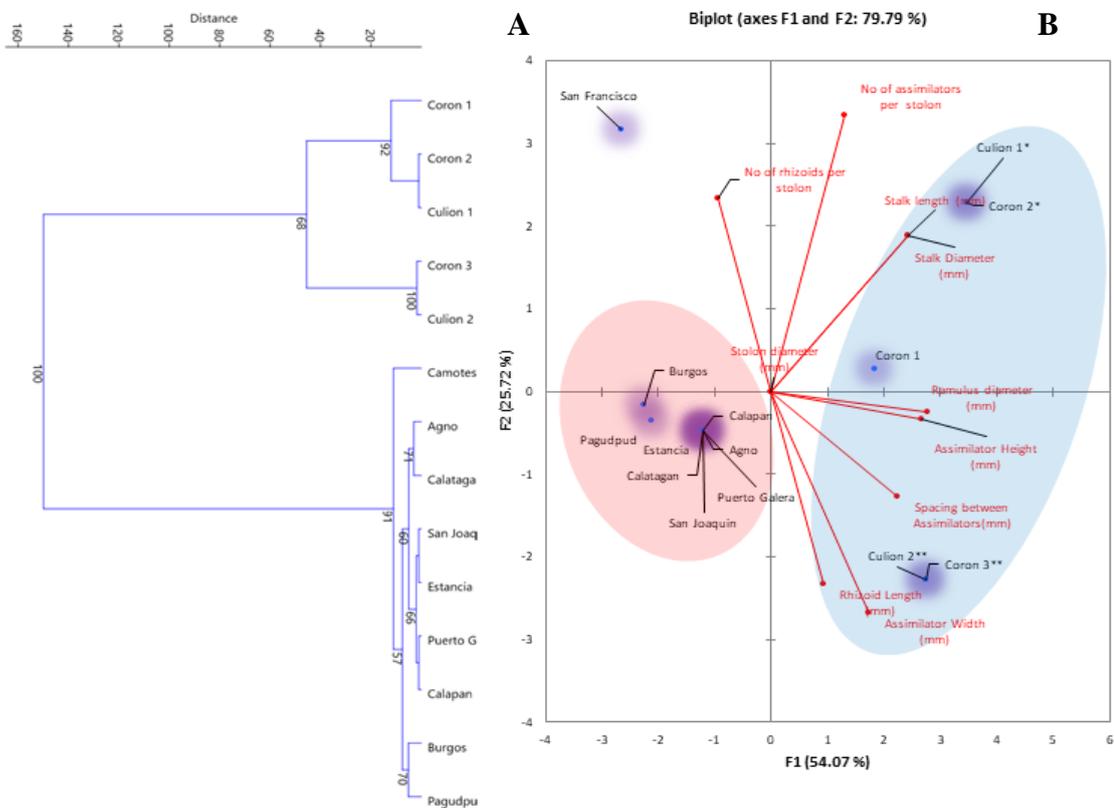


Figure 5. A. Cluster analysis showing the morphological similarities of *C. racemosa* across different sites in the Philippines [PAST v3, Euclidean Similarity Index and Paired group (UPGMA)], and B. Principal component analysis showing relationship of morphometric variables to *C. racemosa* samples across different sites in the Philippines (XLSTAT)

Table 3. Morphometric parameters of assimilators, branchlets, and rhizoids of *C. lentillifera* collected from different sites in the Philippines

Sites	Assimilators				Branchlets			Rhizoids		
	Height (mm)	Width (mm)	Spacing (mm)	No. per stolon	Ramulus diameter (mm)	Stalk length (mm)	Stalk diameter (mm)	Stolon diameter (mm)	Rhizoid length (mm)	No. per stolon
Camotes, Cebu	30-40 ^d	1.00 ^c	6.00 ^c	3.00 ^b	1.00 ^b	1.00 ^b	1.00 ^a	1.00 ^a	2.00 ^a	3.00 ^a
Coron, Palawan	110-130 ^a	3.00 ^a	7.00 ^{cd}	4.00 ^a	2.00 ^a	3.00 ^a	2.00 ^a	2.00 ^a	2.00 ^a	3.00 ^a
Estancia, Iloilo	50-70 ^c	1.00 ^c	10.00 ^a	3.00 ^b	1.00 ^b	1.00 ^b	1.00 ^a	1.00 ^a	1.00 ^a	2.00 ^a
Mactan, Cebu	100-110 ^a	2.00 ^{ab}	10.00 ^{ab}	3.00 ^b	1.00 ^b	2.00 ^{ab}	2.00 ^a	2.00 ^a	2.00 ^a	3.00 ^a
Tablas, Romblon	80-90 ^b	1.00 ^c	10.00 ^{abc}	3.00 ^b	1.00 ^b	1.00 ^b	1.00 ^a	1.00 ^a	2.00 ^a	2.00 ^a

Note: Rank sum between sites that share the same superscript was not significantly different ($P < 0.05$; ANOVA and Kruskal-Wallis Test).

Table 4. Morphometric parameters of assimilators, branchlets, and rhizoids of *C. racemosa* collected from different sites in the Philippines

Sites	Assimilators				Branchlets			Rhizoids		
	Height (mm)	Width (mm)	Spacing (mm)	No. per stolon	Ramulus diameter (mm)	Stalk length (mm)	Stalk diameter (mm)	Stolon diameter (mm)	Rhizoid length (mm)	No. per stolon
Agno, Pangasinan	12-15 ^{abc}	2.0 ^{abc}	8.0 ^{abcd}	2.0 ^{abcde}	2.0 ^{abcde}	1.0 ^{abc}	1.0 ^{abc}	1.0 ^{bc}	10.0 ^a	2.0 ^b
Burgos, Ilocos Norte	10-11 ^{abc}	1.0 ^{bc}	3.0 ^{cd}	2.0 ^{abcde}	1.0 ^{cde}	0.5 ^c	0.5 ^c	1.0 ^{bc}	10.0 ^a	2.0 ^b
Calapan, Oriental Mindoro	10-15 ^{abc}	2.0 ^{abc}	8.0 ^{abcd}	2.0 ^{abcde}	2.0 ^{abcde}	1.0 ^{abc}	1.0 ^{abc}	1.0 ^{bc}	10.0 ^a	2.0 ^b
Calatagan, Batangas	11-15 ^{abc}	2.0 ^{abc}	8.0 ^{abcd}	2.0 ^{abcde}	2.0 ^{abcde}	1.0 ^{abc}	1.0 ^{abc}	1.0 ^{bc}	10.0 ^a	2.0 ^b
Camotes, Cebu	15-20 ^{abc}	1.0 ^{bc}	10.0 ^{abd}	3.0 ^{abc}	1.0 ^{cde}	1.0 ^{abc}	1.0 ^{abc}	1.0 ^{bc}	2.00 ^b	3.0 ^a
Coron 1, Palawan	120-141 ^{abc}	2.0 ^{abc}	20.0 ^{abc}	3.0 ^{abcd}	4.0 ^{bcde}	3.0 ^{bc}	3.0 ^{bc}	1.0 ^{bc}	10.0 ^a	2.0 ^b
Coron 2, Palawan*	110-150 ^{bc}	2.0 ^c	15.0 ^{bcd}	6.0 ^a	5.0 ^a	5.0 ^a	5.0 ^a	1.0 ^c	10.0 ^a	2.0 ^b
Coron 3, Palawan**	160-190 ^a	5.0 ^a	30.0 ^a	1.0 ^{be}	5.0 ^b	2.0 ^{ac}	2.0 ^{ac}	3.0 ^a	10.0 ^a	2.0 ^b
Culion 1, Palawan*	100-150 ^{ac}	2.0 ^{ac}	15.0 ^{abcd}	6.0 ^{ab}	5.0 ^{ac}	5.0 ^{ab}	5.0 ^{ab}	1.0 ^{bc}	10.0 ^a	2.0 ^b
Culion 2, Palawan**	150-189 ^{ab}	5.0 ^{ab}	30.0 ^{ab}	1.0 ^e	5.0 ^{abcd}	2.0 ^{abc}	2.0 ^{abc}	2.0 ^{ab}	10.0 ^a	2.0 ^b
Estancia, Iloilo	11-15 ^{abc}	2.0 ^{abc}	8.0 ^{abcd}	2.0 ^{abcde}	2.0 ^{abcde}	1.0 ^{abc}	1.0 ^{abc}	1.0 ^{bc}	10.0 ^a	2.0 ^b
Pagudpud, Ilocos Norte	11-15 ^{abc}	1.5 ^c	3.0 ^{ad}	2.0 ^{abcde}	1.0 ^{ae}	0.5 ^{bc}	0.5 ^{bc}	1.0 ^{bc}	10.0 ^a	2.0 ^b
Puerto Galera, Oriental Mindoro	11-15 ^{abc}	2.0 ^{abc}	8.0 ^{abcd}	2.0 ^{abcde}	2.0 ^{abcde}	1.0 ^{abc}	1.0 ^{abc}	1.0 ^{bc}	10.0 ^a	2.0 ^b
San Joaquin, Iloilo	12-15 ^{abc}	2.0 ^{abc}	8.0 ^{abcd}	2.0 ^{abcde}	2.0 ^{abcde}	1.0 ^{abc}	1.0 ^{abc}	1.0 ^{bc}	10.0 ^a	2.0 ^b

Note: Rank sum between sites that share the same superscript was not significantly different ($P < 0.05$; ANOVA and Kruskal-Wallis Test). *morphologically identified as *C. racemosa* var. *turbinata* or *C. chemnitzia* var. *turbinata* according to AlgaeBase. **morphologically identified as *C. racemosa* var. *laetevirens* or *C. chemnitzia* var. *laetevirens* according to AlgaeBase

In the case of *C. racemosa*, cluster analysis showed that *C. racemosa* var. *laetevirens* (Coron 3 and Culion 2) from Palawan were the most similar based on morphological traits (Figure 5A). Furthermore, the dendrogram also indicates that the clusters of Coron and Culion in Palawan were different from the clusters in Northern and Southern Luzon. This can be attributed to the high values of morphometric measurements of the sea grapes in Palawan compared to the other sites. Principal component analysis revealed that *C. racemosa* samples from Coron and Culion in Palawan are grouped together since they both exhibit higher values on morphometric parameters, namely assimilator height, assimilator width, spacing between assimilators, number of assimilators on stolon, ramulus diameter, stalk length, stalk diameter and rhizoid length (Figure 5B). In contrast, *C. racemosa* from all the other sites has lower values in terms of number of rhizoids per stolon and are therefore differentiated and grouped separately from Coron and Culion samples. In terms of stolon diameter, however, all the *C. racemosa* samples collected were found to be similar.

Between populations of *C. lentillifera* and *C. racemosa* across different sites in the Philippines, Mann-Whitney test revealed that assimilator height, space between assimilators, ramulus diameter and number of rhizoids on stolon are considered significant characters in studying the morphological plasticity of the sea grapes species in the Philippines (Table 5).

Influence of seawater on sea grape morphology

Pearson correlation and multiple linear regression revealed the physicochemical parameters that are associated with the assimilator height of *C. lentillifera* and *C. racemosa* across different sites in the Philippines (Table 6). Depth and salinity are found significantly associated with the assimilator height of both species, with temperature and dissolved oxygen additionally being significantly associated only with *C. racemosa*. Depth and dissolved oxygen have negative associations with assimilator height while the opposite is true with regards to temperature and salinity.

For *C. lentillifera*, depth and salinity are the only significant variables having opposite effects to assimilator height. As depth (m) decreases, assimilator height (mm) of *C. lentillifera* increases, whereas assimilator height (mm) increases as salinity (ppt) increases. *C. lentillifera* samples from Coron, Palawan and Mactan Cebu are the highest in terms of assimilator height and these are mainly attributed to the high salinity and temperature in these sites (Table 7). On the other hand, populations from Camotes Island in Cebu exhibited the lowest value in terms of assimilator height, primarily due to the high value of depth at the site which is negatively correlated with assimilator height.

For *C. racemosa*, depth and dissolved oxygen are significantly associated with assimilator height despite its negative correlation. Thus, as depth (m) of water and dissolved oxygen (mg/L) decreases, the assimilator height

(mm) of *C. racemosa* increases. On the contrary, temperature and salinity have positively significant coefficients indicating that as temperature (°C) and salinity (ppt) increases, the assimilator height (mm) of *C. racemosa* also increases. *C. racemosa* samples from Coron and Culion in Palawan are the highest in terms of assimilator height and these are mainly attributed to the high salinity, warmer temperature, and lower dissolved oxygen levels in the shallow areas where *C. racemosa* were found (Table 7). Coron and Culion are both neighboring municipalities of Palawan and thus share the same climate type. On the other hand, the short assimilator height of *C. racemosa* populations from Northern Luzon (Pagudpud, Burgos, and Agno) is likely due to high dissolved oxygen levels.

Table 5. Comparison of morphometric parameters (Mean ± SD) of *C. lentillifera* and *C. racemosa* collected from different sites in the Philippines

Morphometric parameters	<i>Caulerpa lentillifera</i> Mean ± SD	<i>Caulerpa racemosa</i> Mean ± SD	P-value
Assimilator height	81±34.17	63.12±69.03	0.006
Assimilator width	1.6±0.89	2.25±1.22	0.879
Space between assimilators	8.6±1.95	12.43±8.72	0.039
Number of assimilators per stolon	3.2±0.45	2.57±1.55	0.125
Ramulus diameter	1.2±0.45	2.79±1.63	0.001
Stalk length	1.6±0.89	1.79±1.52	0.333
Stalk diameter	1.4±0.55	1.79±1.52	0.131
Stolon diameter	1.4±0.55	1.21±0.58	0.581
Rhizoid length	2.0±0.00	9.42±2.14	0.220
Number of rhizoids per stolon	7.8±1.64	2.07±0.27	0.000

Note: (P<0.05; Mann-Whitney Test). Note: P-values in bold are significant values

Table 6. Pearson correlation and multiple linear regression showing physicochemical variables that have direct association and effect on *C. lentillifera* and *C. racemosa* assimilator height from different sites in the Philippines

Species	Height	Coefficients	P> t
<i>C. lentillifera</i>	Depth	-13.90494	0.001
	Temperature	4.034822	0.614
	Salinity	18.59874	0.001
	Dissolved oxygen	0.779445	0.887
<i>C. racemosa</i>	Depth	-13.11592	0.040
	Temperature	15.00358	0.010
	pH	17.24194	0.325
	Salinity	13.18367	0.000
	Dissolved oxygen	-4.853862	0.021

Note: Values in bold are significant values showing significant effect with the assimilator height of sea grapes

Table 7. Means of physicochemical parameters measured from different collection sites of sea grapes in the Philippines

Sites	Physico-chemical parameters							
	D (m)	Temp (°C)	pH	EC (S/m)	S (ppt)	TSS (mg/L)	Tu (mg/L)	DO (ppm)
Calatagan, Batangas	3	28	9.07	0.56	31	10	0.9	4.38
Burgos, Ilocos Norte	2	28.6	7.46	4.76	30	16	0.9	9.17
Pagudpud, Ilocos Norte	2	31.8	7.54	4.82	30	14	0.9	12.63
Agno, Pangasinan	1	30.8	7.52	4.78	33	10	0.9	12.21
Tablas, Romblon	2	28.4	7.75	4.95	35	14	1.0	4.8
Camotes, Cebu	6	28.2	8.07	4.90	35	14	0.9	4.38
Mactan, Cebu	2	28.7	7.81	5.25	35	125	18	4.96
San Joaquin, Iloilo	3	28.7	7.79	4.90	30	11	0.9	4.73
Estancia, Iloilo	2	29.8	8.04	4.29	33	63	8.0	4.79
Calapan, Oriental Mindoro	3	29.9	8.01	4.91	31	9	0.9	4.54
Puerto Galera, Oriental Mindoro	3	31.2	7.82	4.80	31	12	0.9	1.64
Coron, Palawan	2	31.2	8.30	4.83	36	16	0.9	0.93
Culion, Palawan	1.5	31.9	8.16	4.88	34	18	0.9	2.42

Note: *D = depth, Temp = temperature, EC = electrical conductivity, S = salinity, TSS = turbidity, Tu = turbidity, and DO = dissolved oxygen

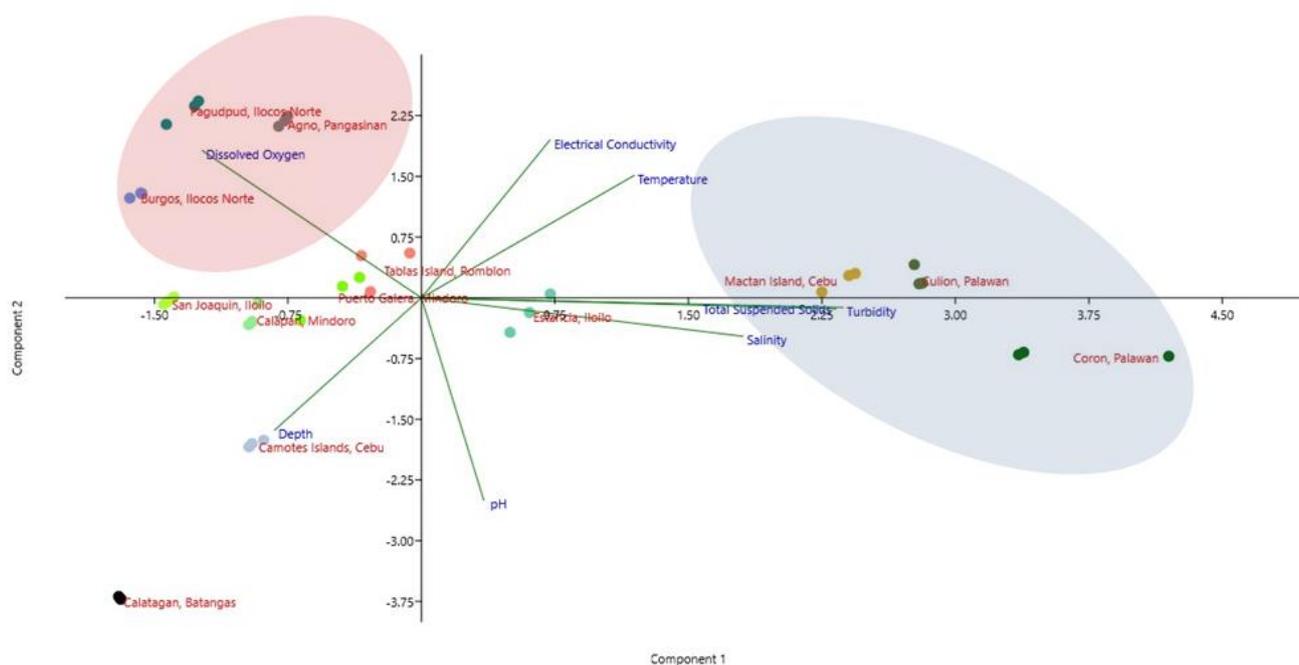


Figure 6. Principal component analysis showing the differences and similarities of different sites in terms of physicochemical parameters of the seawater during peak season of sea grapes in selected regions in the Philippines (PAST v3)

Principal component analysis revealed the differences and similarities of the measured physicochemical variables of seawater at the different sampling sites in the Philippines. Figure 6 shows that physicochemical parameters from Mactan in Cebu, Coron, and Culion in Palawan have higher values on salinity and lower values on depth. The high salinity together and shallow depth in Coron and Culion, Palawan and Mactan, Cebu can possibly account for the high assimilator heights of *C. lentillifera* (Table 3) and *C. racemosa* (Table 4) in these two sites. Thus, sea grapes (*C. lentillifera* and *C. racemosa*) from these two provinces are substantially different from the

other sites and are relatively bigger in terms of size. This is followed by samples from Estancia in Iloilo and Tablas in Romblon. Samples from Northern Luzon (Agno, Burgos, and Pagudpud) and Southern Luzon (Calatagan in Batangas, Calapan and Puerto Galera in Oriental Mindoro) are relatively smaller in terms of size and is mainly due to higher dissolved oxygen or higher depth, which are parameters negatively correlated to assimilator height (Table 6).

In this study, depth and salinity are the primary physicochemical factors contributing to the morphometric differences of both sea grapes species (*C. lentillifera* and *C.*

racemosa) from various regions in the Philippines. This supported the earlier findings that physicochemical factors such as water depth, water temperature, salinity and dissolved oxygen content highly influence growth of *Caulerpa* species (Fernández-García et al. 2011; Zuldin et al. 2019). Light exposure and temperature influenced by depth is an important factor in the increase of frond size and biomass of *Caulerpa* (Peteiro and Freire 2013; Soriano 2012; Guo et al. 2015). Salinity, on the other hand, significantly affects the optimal growth of *Caulerpa* according to previous studies whether in culture or wild indicating its stenohaline nature and salinity tolerance (Pariyawathee et al. 2003; Rabia 2016; Azis et al. 2019; Zuldin et al. 2019).

In conclusion, the results indicate that sea grapes species of the genus *Caulerpa* have the same basic morphology from various regions in the Philippines. However, distinct morphometric variations were observed in the study and show that morphological plasticity exists in sea grapes species (*C. lentillifera* and *C. racemosa*) from selected regions in the Philippines. These are evident in morphometric parameters namely: assimilator height, space between assimilators, ramulus diameter and number of rhizoids on stolon wherein significant differences were found such that these traits varied across sites. This morphological plasticity in sea grapes, particularly on assimilator height, can be discussed in the context of the influence of physicochemical variables of the seawater wherein some parameters are strongly associated while some imposed no direct effect. The physicochemical variables of the seawater observed to have significant relationships with assimilator height are depth, salinity, temperature and dissolved oxygen. Based on the data gathered in this study, sea grapes from selected regions in the Philippines exhibit morphological plasticity in terms of assimilator height, which are primarily influenced by their environment.

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