Morphological Diversity of Sea Grapes (Caulerpa) Present in Selected Coastal Areas in Caraga Region, Philippines

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Morphological Diversity of Sea Grapes (*Caulerpa*) Present in Selected Coastal Areas in Caraga Region, Philippines

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Abstract: This study focuses on the morphological variation of sea grapes (*Caulerpa*) across selected sampling sites in the Caraga Region, Philippines. Two Caulerpa species were identified namely Caulerpa lentillifera and Caulerpa racemosa including its five varieties. The specimens were compared across sites to assess morphological variability and potential environmental adaptation. Analysis revealed significant morphological differences in assimilators, branchlets, and rhizoids, indicating phenotypic adaptability in response to site-specific environmental factors in terms of physico-chemical factors. Principal component analysis, morphological characteristics were grouped based on trait similarities, with *C. racemosa* varieties showing greater variation than *C. lentillifera*. Correlation analysis showed significant relationships ($p<0.05$) between physicochemical parameters and morphological features. Results revealed a positive association with depth in several morphologies, suggesting that deeper water exhibits larger and more developed structures for the *C. lentillifera* species. While *C. racemosa* suggests a significant negative correlation in salinity with its morphology, suggesting that as salinity increases, there is a decrease in morphological traits.

Keywords: Adaptability, Caraga Region, Caulerpa racemosa, Caulerpa lentillifera, Seaweeds

1. INTRODUCTION

Out of the 100 known species of *Caulerpa*, only seven are used for human consumption. Among these are *Caulerpa lentillifera J. Agardh* and *Caulerpa racemosa* (Forsskal) J. Agardh, commonly found in the Philippines, and are known as the leading varieties [1]. These two species are mostly raised in ponds or discovered in the wild. It is commonly known as sea grapes, they are a macroalgal species belonging to the genus *Caulerpa* (*Caulerpaceae*, Chlorophyta). Traded internationally and eaten locally in Southeast Asian nations, including the Philippines [2, 3, 4].

This unicellular green alga with a unique morphological structure, despite lacking transverse cell walls, differentiates into various forms: stolon (horizontal structures), rhizoids (downward-growing extensions), and assimilators (upright fronds). The assimilator consists of a central axis (rachis) with lateral branchlets (ramuli). Historically, these features have been used to distinguish between species. However, due to significant trait variation, molecular analyses are often necessary for accurate species identification [5]. The highest assimilator height of sea grapes was observed in locations with specific environmental conditions, such as higher salinity and temperature in Coron and Culion in Palawan, and lower depth with higher salinity in Mactan, Cebu. This demonstrates how the morphological diversity of sea grapes is intricately linked to the varying environmental conditions they are exposed to, highlighting the adaptability of these species to different marine habitats [6]. This response is known as phenotypic plasticity, which enables organisms to alter their traits, such as form and physiology, in response to their environment. The extent and type of adaptability depend on the organisms, their environment, and how their traits interact [7]. Similarly, plant adaptation develops through ongoing interaction with the environment as they grow [8].

Moreover, *Caulerpa* species vary in their growth morphologies and photosynthetic efficiency, and these variations appear to be correlated with substrate, light intensity, and water velocity [9]. Studies claim that the physicochemical conditions of its habitats, such as salinity, light exposure, depth, and temperature of the water, may have an impact on its morphological differences. These environmental factors play a significant role in shaping the morphology of sea grapes. Thus, these parameters of *Caulerpa* species can be used to study their morphology by assessing the morphological parameters of sea grape through morphometric analysis and correlating them to the physico-chemical components of the seawater in the study site [10].

Up to the present, the morphological diversity of common edible sea grapes in the Caraga region has not yet been fully explored thus, this study was conducted. The researcher conducted the study in four selected areas, namely Hinatuan, Cortes, Barobo, and Carmen, which are some of the coastal municipalities located in the Caraga Region, Philippines. In this study, the researcher investigated the morphological diversity of the common edible sea grape found within the study area. Since there are not many studies conducted on the location site yet, the results of the study could potentially add information to gain an understanding of the morphological diversity of sea grapes.

2. MATERIALS AND METHODS

2.1 Entry protocol and permit acquisition

Before initiating field sampling, the researcher obtained a Gratuitous Permit (GP) as required by the Department of Environment and Natural Resources (DENR) procedure of the Republic of the Philippines, as well as the prior informed consent certificate. Engaging with key stakeholders from the local government and residents is necessary to ensure transparency, obtain necessary permissions, and address any concerns or potential impacts of the research activities on the local community

and environment. Informed consent forms for the survey were also employed before starting the interview.

2.2 Study Area

The samples for the study will be collected from four (4) selected municipalities located in the Caraga Region, namely the municipalities of Barobo, Carmen, Hinatuan, and Cortes (Fig. 1). The municipality of Barobo is a coastal municipality situated in the central region of Surigao Del Sur, which is renowned for its thriving tourism industry. This area boasts several notable tourist attractions, including Turtle Island, Bogac Spring, and the Vanishing Islet. The second study site is the municipality of Carmen, which has marine sanctuaries and was reported to have a sighting of sea turtles. It was declared a critical habitat for marine sea turtles under DENR Administrative Order No. 8 of 2012. Marine sea turtles depend on the available seagrass as a food source. Furthermore, the third study site is the municipality of Cortes, Surigao del Sur, situated along the eastern coast facing the Philippine Sea, which is known to have a wide area of valuable marine coastal resources. The Global Positioning System (GPS) will be used to locate each study station's precise location. QGIS (version 3.16.13-Hannover) was used to create maps of the region of interest for each study station. The fieldwork sampling and data collection started from October 2024 to January 2025.

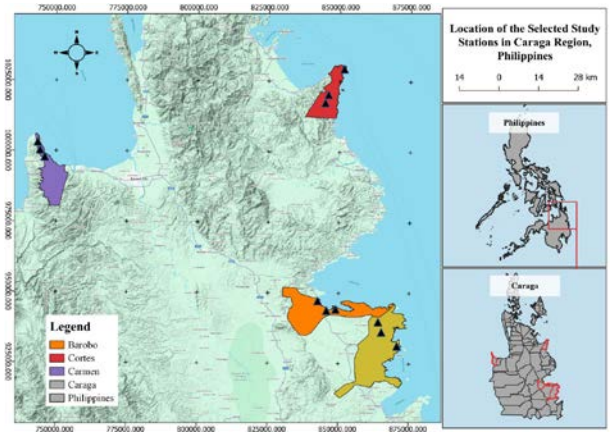

Fig 1. Geographical location of the four study stations.

2.3 Data gathering and analysis

The specimens were obtained from the intertidal and subtidal in the rocky or sandy part of the area below the water surface by snorkeling or wading with the help of the local fisher-folks as guides. Three replicates were collected for each morphologically distinct species found in each barangay using a randomized sampling method. The collection time was conducted during the low tide since seagrapes are exposed and easier to access during this tidal time, and manual harvesting was done using the hand-picking method. Post-harvesting methods were used, such as rinsing the sea grape with seawater to remove any debris and unwanted organisms, then storing it in zip locks to avoid prolonged exposure to direct sunlight to avoid damage that may affect the data in measuring the morphological characterization. Furthermore, baskets were used to gather and transport the specimens. The morphology-based examination and identification were mainly based on Trono [11], and Verlaque et al. [12], adapted from the study conducted by Estrada et al. [6]. The specimens collected undergo both ex-situ and in-situ morphological characterization. The morphometric analysis used in the study was adapted from the study conducted by Estrada et al. [6], as described by Manas et al. [13]. Height, weight, width, spacing, and numbers per stolon (2 cm) were going to be recorded for assimilators or upright fronds; ramuli diameter, stalk length, and stalk diameter were recorded for branchlets; and for rhizoids, stolon diameter, rhizoid length, and number of rhizoids per stolon (2 cm) in collecting this data a vernier caliper and digital weighing scale was used. A digital camera was used for high-resolution, clear, and detailed images in taking photographs of the specimen that was collected.

The assimilators are made up of branchlets known as ramuli, which are the edible portions of the species and resemble "grapes". At its ventral side, a horizontal stolon that branches produces many assimilators and rhizoids for attachment. The water physicochemical parameters of seawater were recorded using a Hannah HI98195-web multiparameter water quality tester by submerging the probes in the water. This includes seawater temperature (°C), salinity (ppt), which is the salt concentration in the water, dissolved oxygen (mg/L), which is the oxygen available in the water, conductivity, and pH, which determines the acidity or alkalinity of the water. The depth from the surface water to the substratum of the sampling zones was measured using a Secchi disk. The readings were taken at the sites where the sea grape samples were collected. Analysis of Variance (ANOVA) was used in analyzing the significant differences in morphometric data of Seagrapes across different study sites. For correlation in morphometric data and physicochemical parameters, Spearman's correlation was used. For descriptive analysis of getting the frequency in the data gathered in the survey for human consumption habits. JASP version 0.19.3 software was utilized in analyzing the data with the p-value reference $p < 0.01$, < 0.05, and 0.001.

3. RESULTS AND DISCUSSION

Sea Grape's Identification and Morphological Characteristics

The species identification was carried out primarily through morphological analysis. In this study, two species of *Caulerpa* were identified, namely, *C. lentillifera J. Agardh* and *Caulerpa racemosa (Forsskal) J. Agardh*, along with five varieties of *C. racemosa*, which include *laetevirens, chemnitzia, turbinata, cylindracea,* and the general *C. racemosa.*

The morphological characteristics of the two *Caulerpa* species were assessed, focusing on several key traits, as referenced in Algae Base by Guiry & Guiry [14]. Since *Caulerpa* species are environmentally controlled by phenotypic plasticity, these lead to much confusion regarding the naming of species, there is a large number of synonyms and a classification scheme involving sub-species, varieties, forms, and "ecads" [15]. *C. chemnitzia* (Figure 2, C-D), which was previously named *C. racemosa* var. *laetevirens* (Montagne) Weber-van Bosse, is described as usually very crowded and radially arranged ramuli, which are highly variable, clavate to turbinate to peltate. It also often takes many forms on a single assimilator, as noted by Belton et al. [15]

C. *racemosa* var. *cylindracea* (Sonder) (Fig. 3, C-B). It is described as having a slender thallus with thin, closely arranged rhizoids and a slightly swollen base above the stolon. Its axes have radially or distichously arranged, uncrowded, clavate to cylindrical branchlets. Unlike other varieties, it lacks trumpet- or shield-shaped branchlets and is identified by its narrow rhizoids, inflated basal axes, and distinctive branchlet arrangement [12], while *C. racemosa* var. *turbinata* (Figure 3 A-B) has uncrowded ramuli that are clavate with flattened ends. Then, *C. racemosa* var. *laetevirens* has crowded ramuli that are cylindrical to gradually clavate (Figure 3 E-F). Moreover, *C. racemosa* (Fig. 3, A-B), which is characterized by assimilator features, ramuli that are highly variable in form, either fully or partially stalked. Their arrangement varies widely, appearing irregularly, in paired rows, in several rows, or overlapping layers, highlighting the morphological adaptability of the structure [4]. This is also the same with *C. lentillifera* (Figure 2, E-F), which is described as having upright fronds with grape-like, vesicular ramuli attached to creeping stolons by rhizoids [16]. Various samples collected were compared to detect patterns of morphological adaptation across the different variants and environmental conditions by measuring their morphological parameters.

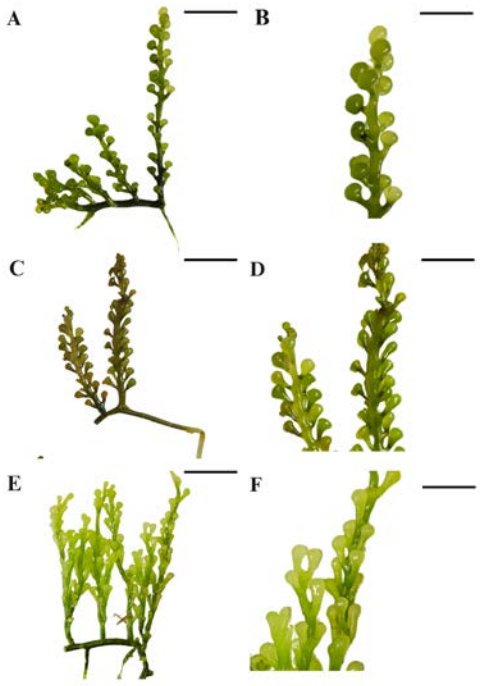

Fig. 2 Identified sea grape species variants across different sites: (A-B) *Caulerpa racemosa* and its detailed part of assimilator, (C-D) *Caulerpa racemosa var. cylindracea* and detailed part assimilator, *C. racemosa var. laetevirens* (E-F). Scale bar 1mm.

Morphological Differences Among Sea Grape Variants

Caulerpa racemosa

Significant morphological differences in assimilators, branchlets, and rhizoids were observed across the populations of *C. racemosa* from various sampling sites (Table 1), highlighting how these characteristics vary in response to the distinct environmental conditions at each location. Most variants of *C. racemosa* exhibit significant morphological differences across different sites, where *C. racemosa var. chemnitzia* from San Juan, Hinatuan, shows the highest mean weight. In terms of assimilator height, samples from Rizal 3, which is the C. *racemosa* var. *turbinata,* display the tallest assimilators, ranging from 102.8 to 117.4 mm, with significant differences compared to other *C. racemosa* variant samples from different sites.

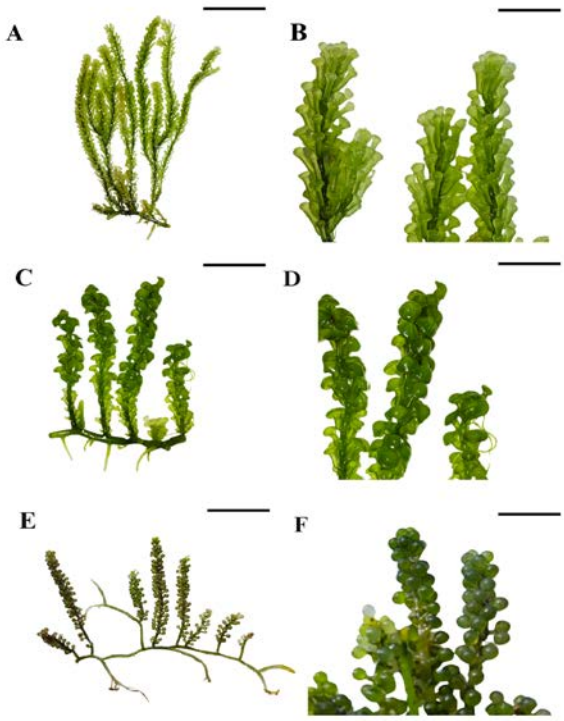

Fig. 3 Identified sea grape species variants across different sites: (A-B) *C. racemosa var. turbinata* and its detailed part of assimilator, (C-D) *C. racemosa var. chemnitzia* and its detailed assimilator, (E-F) *C. lentillifera* and its detailed assimilator. Scale bar 1mm.

Assimilator width was highest in Rizal 2, Barobo samples, which is the *C. racemosa* var. *cylindracea*, while the widest spacing was found in *C. racemosa* in Kinayan, Barobo. Ramuli per stolon showed no significant differences across the sites. Regarding the ramulus diameter, the largest measurements were found in *C. racemosa var. chemnitzia* in Wakat, Barobo, while stalk length and stolon diameter were highest in *C. racemosa* var. *chemnitzia* in Cambatong, Hinatuan, and stalk diameters were higher in San Juan, Hinatuan samples of the same C*aulerpa* variant, while rhizoid length was longest in *C. racemosa* samples from Kinayan, Barobo, and the highest number of rhizoids per stolon was observed in *C. racemosa* in Vinapor, Carmen.

Principal component analysis reveal distinct morphological variations in *C. racemosa* across different sites where samples were collected (Fig. 4). Results show samples such as Rizal 2, Cambatong, and Talisay are clustered together since they both exhibit the most robust morphological traits, characterized by larger stolon

diameter, greater weight, and longer stalks, which indicates a favorable growth condition for this morphology.

Meanwhile, Wakat, Gosoon, and Vinapor are clustered together, exhibiting the smallest and least developed *Caulerpa* morphologies, suggesting thinner stolons, weight, height, and spacing. Samples from Uba 1 stand out as having the highest rhizoid and assimilator density, which could imply greater nutrient absorption efficiency. Tigao and Kinayan display a more balanced morphology value, lacking extreme values in either direction. Samples from Mabahin and Rizal 3 exhibit relatively lower values for most traits, with thinner stolons and fewer assimilators per stolon. Moreover, San Juan shares similarities with Cambatong and Talisay, showing moderate to large stalks and stolons.

These findings show a notable morphological difference between sites, indicating that *C. racemosa* growth and structure may be affected by environmental conditions or harvesting activities in different locations. Moreover, as previous studies mentioned, water quality is a key factor that can influence the growth of *C. racemosa* [17]. The morphological and physiological traits of *C. racemosa* can vary in response to local physico-chemical conditions, demonstrating a high degree of flexibility that contributes to its ecological success across diverse environments. This adaptability accounts for the observed morphological differences among populations from different sites, as it enables the species to tolerate and thrive across a wide range of habitats, thereby enhancing its capacity for colonization and invasion of new areas [18,19,20].

Table 1. The summary of the substrate type across different sampling sites in the Caraga region, Philippines

Sampling site	Substrate type
Rizal	Sandy
Kinayan	Sandy
Wakat	Sandy-muddy, rocky
Uba	Sandy-muddy
Tigao	Sandy-muddy
Mabahin	Sandy-muddy
San Juan	Sandy
Cambatong	Sandy-muddy
Talisay	Sandy-muddy
Gosoon	Sandy-muddy
Vinapor	Sandy
Cahayagan	Muddy, rocky

According to Jayusri et al. [21], the morphological variants of *C. racemosa* result from environmental differences within and between habitats, with sandy substrates identified as the more favorable habitat for this species, since small particle size facilitates nutrient absorption and attachment by the roots. The sandy-muddy and sandy substrates of the sampling sites (Table 1) may explain the observed morphological variations found in *Caulerpa*, as the species likely adapts its form in response to different substrate types. This is supported by previous studies indicating that substrate type can influence growth and lead to distinct morphological characteristics.

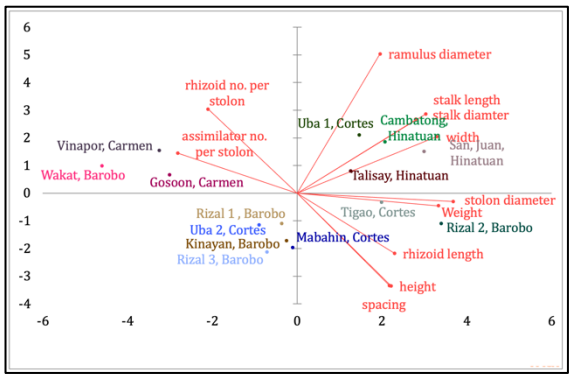

Fig. 4 PCA biplot results showing the morphological variation of *C. racemosa* across different study sites in the Caraga Region, Philippines.

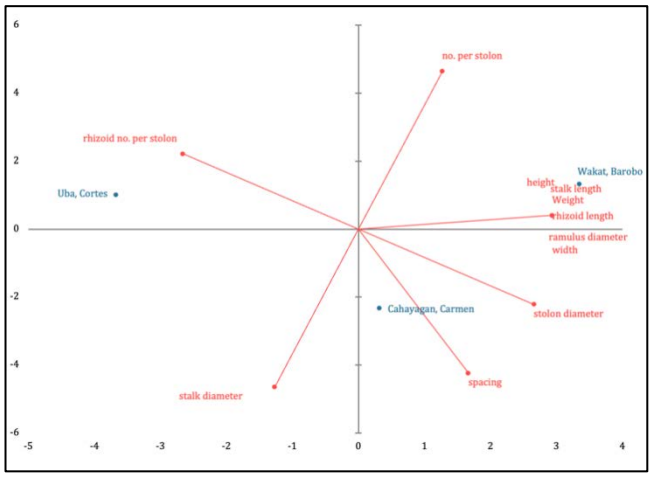

Fig. 5 PCA biplot results showing the morphological variation of *C. lentillifera* across different study sites in the Caraga Region, Philippines

The result of the mean morphometric characteristics of *C. lentillifera* collected across three different sites, including the Cahayagan (Carmen), Uba (Cortes), and Wakat (Barobo). This reveals notable site-specific variations. Among the sites, Wakat, Barobo (Figure 5, A-B) exhibited the most developed morphological traits, with the highest values for weight (2.5 g), height (66.97 mm), and width (8.2 mm). In contrast, Uba, Cortes showed the lowest measurements for most parameters, indicating less favorable conditions for growth. However, traits such as spacing, number of ramuli per stolon, and stolon diameter showed minimal variation across all sites.

The principal component analysis further supports these findings, confirming significant morphological variation among the sites (Figure 5). Samples from Wakat, Barobo consistently displayed the largest and heaviest structures, including longer stalks, wider and taller assimilators, greater rhizoid length, and larger ramulus diameter. These traits suggest that Wakat provides more favorable environmental conditions for *C. lentillifera*. On the other hand, Uba exhibited smaller and thinner structures, which may reflect more limiting environmental factors. Cahayagan showed intermediate morphometric values among the three sites, suggesting moderately supportive

conditions for growth.

These variations imply that local environmental factors—such as substrate type, water quality, and nutrient availability—significantly influence the morphology and development of *C. lentillifera*. The sandy-muddy substrate in Wakat, Barobo (Table 1) contributes to its enhanced growth performance, although similar substrate types are present in both Cahayagan and Uba. What likely distinguishes Wakat is the presence of reef flats that remain submerged during low tide and are characterized by calm waters, conditions considered favorable for this species [22]. Overall, the results indicate that *C. lentillifera* grows best in Wakat, Barobo, where environmental conditions appear most favorable, and it adapts better compared to the other sites.

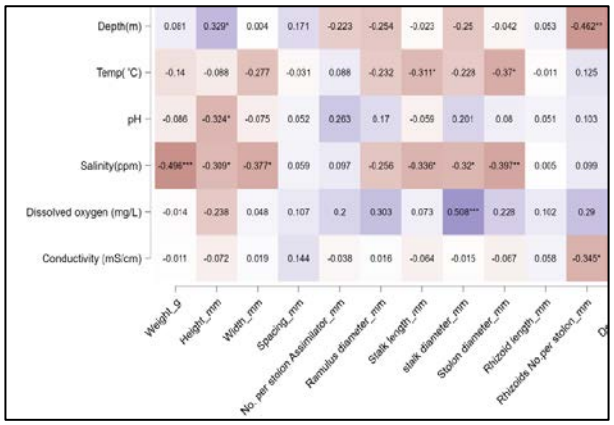

Fig. 6 Spearman's rho heat-map results showing the relationships between morphological traits of *C. racemosa* and physico-chem variables across study sites. Correlation coefficients are color-coded with blue shades (positive correlation) and red shades (negative correlation). Levels of statistical significance are denoted by asterisks ($p < 0.05$, **p** < 0.01, **p** < 0.001).

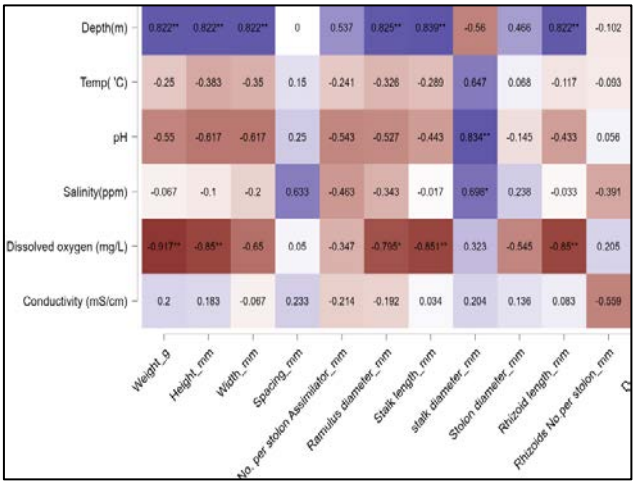

Fig. 7 Spearman's rho heat map results showing the relationships between morphological traits of *C. lentillifera* and physico-chem variables across study sites. Correlation coefficients are color-coded with blue shades (positive correlation) and red shades (negative correlation). Levels of statistical significance are denoted by asterisks ($p < 0.05$, **p** < 0.01, **p** < 0.001).

Influence of Seawater Parameters on *Caulerpa* Morphology

Correlation analysis revealed that salinity plays a significant role in shaping the morphology of *C. racemosa* (Figure 6). Higher salinity was strongly and negatively associated with weight (r = –0.496), width (r = –0.377), stalk diameter (r = –0.320), stalk length (r = –0.336), and stolon diameter (r = –0.397). These results suggest that elevated salinity may suppress structural growth. Sites such as Vinapor and Wakat, characterized by higher salinity, exhibited notably reduced morphological features in their *C. racemosa* samples, including thinner stolons and lower biomass. These findings are consistent with previous studies emphasizing the stenohaline nature of *Caulerpa* and its sensitivity to salinity fluctuations [6]. Salinity is also one of the most significant abiotic environmental factors influencing the growth and spread of algae [23]. Dissolved oxygen also showed a positive relationship with several morphological features of *C. racemosa*. For instance, stalk diameter (r = 0.508, p < 0.001) and the number of rhizoids per stolon (r = 0.333) increased with oxygen availability, suggesting that oxygen-rich environments promote more robust thallus structures. Sites such as Tigao, Cahayagan, and Uba, which showed higher oxygen levels (Table 10), had thicker stalks and greater rhizoid development. Depth, on the other hand, correlated positively with thallus height but negatively with rhizoid number (r = –0.462), implying that deeper waters may encourage vertical growth while limiting anchorage structures due to reduced light or oxygen levels. For *C. lentillifera* this *caulerpa* species exhibited different trends (Fig. 7). Morphological traits such as weight, height, width, ramulus diameter, and rhizoid length were positively correlated with depth, suggesting that this species may thrive better in deeper, more stable environments. Sites like Wakat, Barobo supported larger and more developed *C. lentillifera* specimens, possibly due to their lower oxygen conditions. Dissolved oxygen showed a strong negative correlation with multiple morphological traits including weight (r = –0.917), height (r = –0.85), stalk length (r = –0.851), and rhizoid length (r = –0.85) indicating that high oxygen levels may not favor this species' growth, perhaps due to oxidative stress or other physiological factors. However, previous studies also claimed that these morphological traits are considered adaptive responses to reduced light availability at depth. Frond elongation and decreased frond density are commonly observed strategies that help enhance light absorption in low-light environments [24]. Principal Component Analysis (Figure 8) further supports these findings by grouping sites according to environmental characteristics. San Juan, Kinayan, Cambatong, Rizal, and Wakat clustered together under the influence of low salinity and conductivity across the site. Talisay, Hinatuan stood apart with deeper waters and low dissolved oxygen. Vinapor and Gosoon were associated with pH and temperature, while Tigao, Cahagayan, and Uba aligned with higher dissolved oxygen. These groupings support the idea that salinity, conductivity, and dissolved oxygen are the dominant environmental variables influencing *Caulerpa* morphology. The correlation and PCA results underscore the ecological plasticity of both *Caulerpa* species. While *C. racemosa* appears more sensitive to salinity and benefits from oxygen-rich conditions, *C. lentillifera* shows greater adaptability to depth and low-oxygen

environments. Although the dissolved oxygen level in Wakat is 0.30 mg/L, it is very low and falls outside the suitable range for *Caulerpa* growth when compared to other studies where dissolved oxygen levels of ≥5 mg/L are considered appropriate for both sea bass and sea grapes [25]. These differences in morphological responses reflect species-specific strategies for coping with environmental gradients, consistent with previous studies on their adaptive physiology [26, 10]. In addition, Harwanto et al. [17], also highlight the species' broad tolerance to varying salinity levels, which likely contributes to its adaptability in different marine environments. Ultimately, environmental parameters, particularly salinity, oxygen availability, and depth, emerge as critical factors shaping the phenotypic variation and site-specific adaptation of sea grapes in this area.

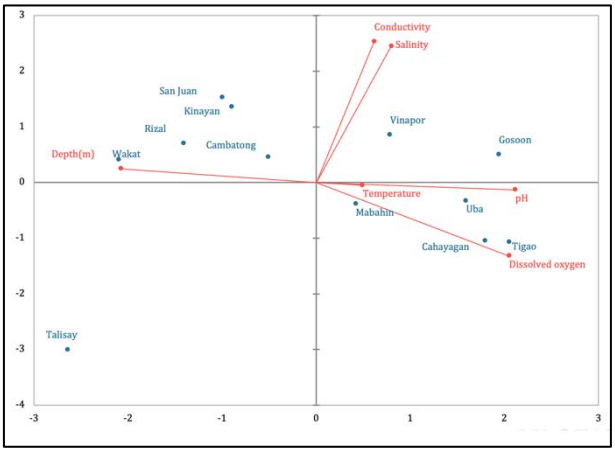

Fig. 8 PCA biplot results of the physicochemical parameters of seawater across different sites in the Caraga region, Philippines

With some places, like Wakat and Uba, supporting both *C. racemosa* and *C. lentillifera*, this distribution exhibits the diverse presence of *C. racemosa* from various areas. The variety of *C. racemosa* species seen in these regions raises the possibility that the species has adapted to the local environment. This comparison reveals how each *Caulerpa* variant has adjusted to its habitat, providing insight into the ecological factors that affect their growth and morphology [6].

4. REFERENCES

[1] W. Pan-utai, P. Satmalee, S. Saah, Y. Paopun, and M. Tamtin, "Brine-processed *Caulerpa lentillifera* macroalgal stability: Physicochemical, nutritional and microbiological properties," *Life*, vol. 13, no. 11, p. 2112, 2023, doi: 10.3390/life13112112.

[2] V. T. Nguyen, J. Ueng, and G. Tsai, "Proximate Composition, Total Phenolic Content, and Antioxidant Activity of Seagrape (Caulerpa lentillifera)," *J. Food Sci.*, vol. 76, no. 7, 2011. doi: 10.1111/j.1750-3841.2011.02289.x.

[3] G. G. Delan et al., "The Influence of Habitat on the Quality Characteristics of the Green Macro Alga Caulerpa lentillifera Agardh (Caulerpaceae, Chlorophyta)," *Trop. Technol. J.*, vol. 19, no. 1, p. 10, 2015. doi: 10.7603/s40934-015-0010-4.

[4] J. L. Estrada and M. L. Dionisio-Sese, "Sea Grapes (Caulerpa spp.) (Chlorophyta: Caulerpaceae) from Coron, Northern Palawan, Philippines with Notes on Their Harvest and Production," Nov. 26, 2020. [Online]. Available: https://li01.tci-thaijo.org/index.php/tnh/article/view/243187

[5] G. S. Belton, S. G. Draisma, W. F. P. Van Reine, J. M. Huisman, and C. F. D. Gurgel, "A taxonomic reassessment of Caulerpa (Chlorophyta, Caulerpaceae) in southern Australia, based on tuf A and rbc L sequence data," *Phycologia*, vol. 58, no. 3, pp. 234–253, 2019. doi: 10.1080/00318884.2018.15428.

[6] J. L. Estrada, S. N. Bautista, and M. L. Dionisio-Sese, "Morphological variation of two common sea grapes (Caulerpa lentillifera and Caulerpa racemosa) from selected regions in the Philippines," *Biodiversitas J. Biol. Divers.*, vol. 21, no. 5, 2020. doi: 10.13057/biodiv/d210508.

[7] D.W. Pfennig, *Phenotypic Plasticity & Evolution*. CRC Press, 2021. [Online]. Available: https://doi.org/10.1201/9780429343001

[8] Y. Wu and Y. Wu, "The diversification of adaptive strategies for karst-adaptable plants and the utilization of plant resources in karst ecosystems," *Agronomy*, vol. 13, no. 8, p. 2135, 2023. [Online]. Available: https://doi.org/10.3390/agronomy13082135

[9] W. Koositra, "Molecular phylogeny of the genus Caulerpa (Caulerpales, Chlorophyta) inferred from chloroplast tufa gene1," *Szn*, 2021. [Online]. Available:https://www.academia.edu/47773379/molecular_phylogeny_of_the_genus_caulerpa_caulerpales_chlorophyta_inferred_from_chloroplast_tufa_gene1?Email_work_card=view-paper

[10] S. Sihono, B. S. B. Utomo, and N. Nurhayati, "Molecular Identification, Nutritional Profile and Heavy Metals Content of Edible Caulerpa from Binuangeun Coast, Banten," *Squalen Bull. Mar. Fish. Postharvest Biotechnol.*, vol. 16, no. 2, pp. 83–92, 2021. doi: 10.15578/squalen.525.

[11] G. C. Trono Jr, *Manual on seaweed culture. 2: Pond culture of Caulerpa and 3: Pond culture of Gracilaria*, 1988.

[12] M. Verlaque, C. Durand, J. M. Huisman, C. Boudouresque, and Y. L. Parco, "On the identity and origin of the Mediterranean invasive Caulerpa racemosa (Caulerpales, Chlorophyta)," *Eur. J. Phycol.*, vol. 38, no. 4, pp. 325–339, 2003. doi: 10.1080/0967026031000161259 2.

[13] H. M. Manas, G. Deshmukhe, G. Venkateshwarlu, S. K. Chakraborty, A. K. Jaiswar, P. Mugaonkar, and S. A. Dar, "Morphological comparison of different Caulerpa J.V. Lamouroux species along Maharashtra and Gujarat coast, India," *Indian Journal of Geo-Marine Sciences*, vol. 44, no. 5, pp. 732–737, 2015.

[14] M. D. Guiry and G. M. Guiry, "AlgaeBase," National University of Ireland, Galway, 2025. [Online]. Available: https://www.algaebase.org

[15] G. S. Belton, W. F. P. Van Reine, J. M. Huisman, S. G. A. Draisma, and C. F. D. Gurgel, "Resolving phenotypic plasticity and species designation in the morphologically challenging Caulerpa racemosa–peltata complex (Chlorophyta, Caulerpaceae)," *J. Phycol.*, vol. 50, no. 1, pp. 32–54, 2013. doi: 10.1111/jpy.12132.

[16] L. E. Stuthmann, B. Brix Da Costa, K. Springer, and A. Kunzmann, "Sea grapes (Caulerpa lentillifera J. Agardh, Chlorophyta) for human use: Structured review on recent research in cultivation, nutritional value, and post-harvest management," *J. Appl. Phycol.*, vol. 35, no. 6, pp. 2957–2983, 2023. doi: 10.1007/s10811-023-03031-x.

[17] D. Harwanto, P. Saputro, T. Susilowati, A. H. C. Haditomo, and S. Windarto, "Effect of different N:P ratios application on the cultivation media for the growth and fiber content of Caulerpa racemosa reared in tarpaulin ponds," *AACL Bioflux*, vol. 13, no. 5, pp. 3117–3125, 2020.

[18] M. Darmawan, N. P. Zamani, H. E. Irianto, and H. H. Madduppa, "Molecular characterization of Caulerpa racemosa (Caulerpales, Chlorophyta) from Indonesia based on the plastid tufA gene," *SQUALEN Bull. Mar. Fish. Postharvest Biotechnol.*, vol. 16, no. 3, pp. 101–109, 2021. doi: 10.15578/squalen.588.

[19] R. Raniello, M. Lorenti, C. Brunet, and M. Buia, "Photosynthetic plasticity of an invasive variety of Caulerpa racemosa in a coastal Mediterranean area: Light harvesting capacity and seasonal acclimation," *Mar. Ecol. Prog. Ser.*, vol. 271, pp. 113–120, 2004. doi: 10.3354/meps271113.

[20] J. Santamaría, R. Golo, E. Cebrian, M. García, and A. Vergés, "Stressful conditions give rise to a novel and cryptic filamentous form of Caulerpa cylindracea," *Front. Mar. Sci.*, vol. 8, 2021. doi: 10.3389/fmars.2021.548679.

[21] J. Jayusri, N. N. Cokrowati, and N. Diniarti, "Cultivation of seaweed Caulerpa racemosa using different substrates on a laboratory scale," *Asian J. Aquat. Sci.*, vol. 6, no. 3, pp. 441–446, 2023. doi: 10.31258/ajoas.6.3.441-446.

[22] T. Tran, "Sea grapes (Caulerpa lentillifera)," *Vietnamese Seaweed*, June 3, 2015. [Online]. Available:https://seaweedvietnam.wordpress.com/2015/06/01/sea-grapes-caulerpa-lentillifera/.

[23] R. Gerundio, R. Orbita, and S. Ronnah Orbita, "Growth, biomass and productivity of green seaweed Caulerpa lentillifera (J. Agardh) at different stocking densities," *Int. J. Biol.*, vol. 16, no. 4, pp. 290–298, 2020. doi: 10.12692/ijb/16.4.290-298.

[24] S. E. Voerman, T. M. Glasby, W. E. Gladstone, and P. E. Gribben, "Morphological variation of a rapidly spreading native macroalga across a range of spatial scales and its tolerance to sedimentation," *Mar. Environ. Res.*, vol. 147, pp. 149–158, 2019. doi: 10.1016/j.marenvres.2019.02.017.

[25] R. Jongjaraunsuk, K. Khaodon, S. Rermdumri, A. Intarachart, and W. Taparhudee, "Nitrogen budget and the effects of sea grape (Caulerpa lentillifera) density on the water quality and growth performance of Asian seabass (Lates calcarifer) in a polyculture system," *Fishes*, vol. 10, no. 4, p. 163, 2025. doi: 10.3390/fishes10040163.

[26] Mosquera-Murillo, "Effect of salinity on growth of the green alga Caulerpa sertularioides (Bryopsidales, Chlorophyta) under laboratory conditions," *Hidrobiológica*, vol. 26, no. 2, pp. 277–282, 2016. doi:10.24275/uam/izt/dcbs/hidro/2016v26n2/mosquera.