

Influence of physicochemical environmental factors on morphometric characteristics of macroalgae from Ambon Island, Indonesia

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Abstract. *Liline S, Rumahlatu D, Zubaidah S, Salmanu S, Sangur K. 2024. Influence of physicochemical environmental factors on morphometric characteristics of macroalgae from Ambon Island, Indonesia. Biodiversitas 25: 1436-1453.* Macroalgae are an essential part of the marine biodiversity of Ambon Island, requiring thorough investigation for conservation and cultivation purposes. Therefore, this study aimed to identify macroalgae and analyze the relationship of environmental physicochemical factors to morphometric characteristics of macroalgae from the coastal waters of Ambon Island, Maluku Province, between June and July 2023. Sampling was performed at four locations, i.e., Hutumuri, Alang, Aer Low, and Suli Villages, followed by laboratory morphometric identification and measurements. The results showed significant variations in the physicochemical environmental factors of the four locations, featuring temperatures ranging from 25.00-30.05°C, pH of 7.00-8.34, salinity of 31.00-32.00, and dissolved oxygen (DO) of 6.00-15.27. Furthermore, the substrate in each location differed, presenting sequentially as sandy coral, coral, sandy coral, and mud sand. 11, 10, 6, and 25 species were found in Hutumuri, Alang, Aer Low, and Suli, respectively. Each species, with distinct morphological characteristics and morphometric sizes, was distributed across the Chlorophyta, Ochrophyta, and Rhodophyta classes. These observations provided crucial insights into the intricate relationship between environmental factors and morphometric characteristics, including full length, thallus width, and length, as well as holdfast length and width of both same-species and different macroalgae populations in Ambon Island.

Keywords: Ambon Island, macroalgae, morphometric, physicochemical environment

INTRODUCTION

Ambon Island, situated between the Seram and Banda seas, is renowned for its rich marine biodiversity in the Maluku Province. Geographical positioning significantly influences the presence of diverse marine organisms, including macroalgae (Lumuindong et al. 2023; Limmon et al. 2023; Pattikawa 2018). Macroalgae, multicellular eukaryotes capable of photosynthesis, generate over 40% of the world's oxygen needs (Guo et al. 2022; Kumar et al. 2022; Florez et al. 2017). Its significant role is played in the water ecosystem by serving as a food source (Sheikhzadeh et al. 2022), functioning as a habitat and a source of nourishment for epifauna (Navarro-Barranco et al. 2019), providing essential sustenance for fish (Manikandan et al. 2022; Rouhani et al. 2022), sources as pigments, proteins, polysaccharides, and lipids (Arias et al. 2022; Pereira et al. 2017), function as economic value and benefit humans as medicine, foodstuffs, and industrial raw materials (Afreen et al. 2023; Srimariana et al. 2020), and natural fertilizers, and liquid waste treatment (Kustantinah et al. 2022; EL Boukhari et al. 2020; Barbot et al. 2016). Macroalgae reside in coastlines and oceans, extending from intertidal zones to depths exceeding 200 meters (Duarte et al. 2022). Indonesia contains 6.42% of the total macroalgae biodiversity worldwide, covering 1.2 million hectares (Sofiana et al. 2022; Melsasail et al. 2018).

Environmental factors greatly influence the life of macroalgae in marine waters. Warm tropical waters, enriched with sunlight and physicochemical factors, contribute to the abundance of organisms (Mushlihah et al. 2021). Sangil et al. (2018) stated the significant impact of temperature variations on subtidal macroalgae community structure in the Eastern Atlantic Islands. According to Wahl et al. (2021), temperature, salinity, and oxygen availability constantly fluctuate, causing stress that affects marine organisms' interaction with the environment. Seawater's acidity or pH level ranging from 6.87-8.12 and a temperature of 25.9-26.6°C are crucial for photosynthesis (Fitrihastuti et al. 2023; (Rugebregt et al. 2020). Salinity and CO₂ levels also play important roles in determining growth rate (Fabricius et al. 2023; Pei et al. 2021). Handayani et al. (2023) found that the diversity of macroalgae in the Seribu Islands was influenced by salinity, temperature, brightness, depth, and current speed (physical factors), as well as nitrate, orthophosphate, heavy metal levels, and pH (chemical factors). Apart from environmental factors, the substrate performs an essential role by serving as a surface for macroalgae attachment by holdfasts, promoting efficient growth. Furthermore, the substrate's type, size, and stability significantly influence these organisms' presence and diversity (Sangil et al. 2021; Lin et al. 2018).

Studying morphometric characteristics is crucial for the breeding of macroalgae and assessing genetic traits (Umanzor et al. 2021). Research studies on macroalgae morphometrics in Indonesian marine waters have been conducted Raza'I et al. (2021) reported the morphometrics of *Caulerpa racemose* on Bintan Island for tallus length, stolon length, and stolon grains. Sumandiarsa et al. (2021) reported a correlation of DO and salinity to the distance from holdfast to talus branching and a correlation of temperature and brightness to the diameter of the holdfast *Sargassum polycystum* of Tidung, Sebesi, and Bintan Island. Kase et al. (2019) reported that the environment influences morphometrics of several macroalgae from Chlorophyta, Ochrophyta, and Rhodophyta in the Dara Mara marine. The study of macroalgae morphometrics in Ambon Island waters is crucial, backed by morphological studies of the macroalgae species found in the island's waters. The morphological characteristics of macroalgae observed are types of thallus in the form of sheets, tubes, fibers, grapes, stolons, and holdfasts. Morphometric measurements are crucial for understanding macroalgae's morphological variation, but the relationship between physical environmental factors and their characteristics remains unexplored.

Administratively, Ambon Island consists of two regencies, namely Ambon City and Central Maluku, which comprise the waters of Hutumuri, Aer Low, Alang, and Suli Villages, respectively. Varying elevation, slope

characteristics, and substrate in these locations influence macroalgae biodiversity (Sangil et al. 2021; Steigleder et al. 2019). Therefore, this study aimed to analyze the biodiversity of macroalgae from the coastal waters of Ambon Island, Maluku Province, and the relationship of physicochemical factors to their morphometrics. Morphological studies on Ambon Island macroalgae can enhance their economic value and facilitate structural studies between species, making them valuable for food and industry. Hence, this study reveals environmental physicochemical factors, macroalgae identification, and macroalgae morphometric measurements.

MATERIALS AND METHODS

Study locations

This study was carried out from June to July 2023 in the waters of Hutumuri (H), Aer Low (AL), Alang (A), and Suli (S) Villages of Ambon Island, Maluku, Indonesia. The geographical conditions of the four data collection locations are presented in Figure 1 and Table 1. The sampling location using probability sampling techniques is according to the researchers' considerations. The intended consideration is that the location has a lot of macroalgae diversity; the location is easy to reach and is safe for sampling.

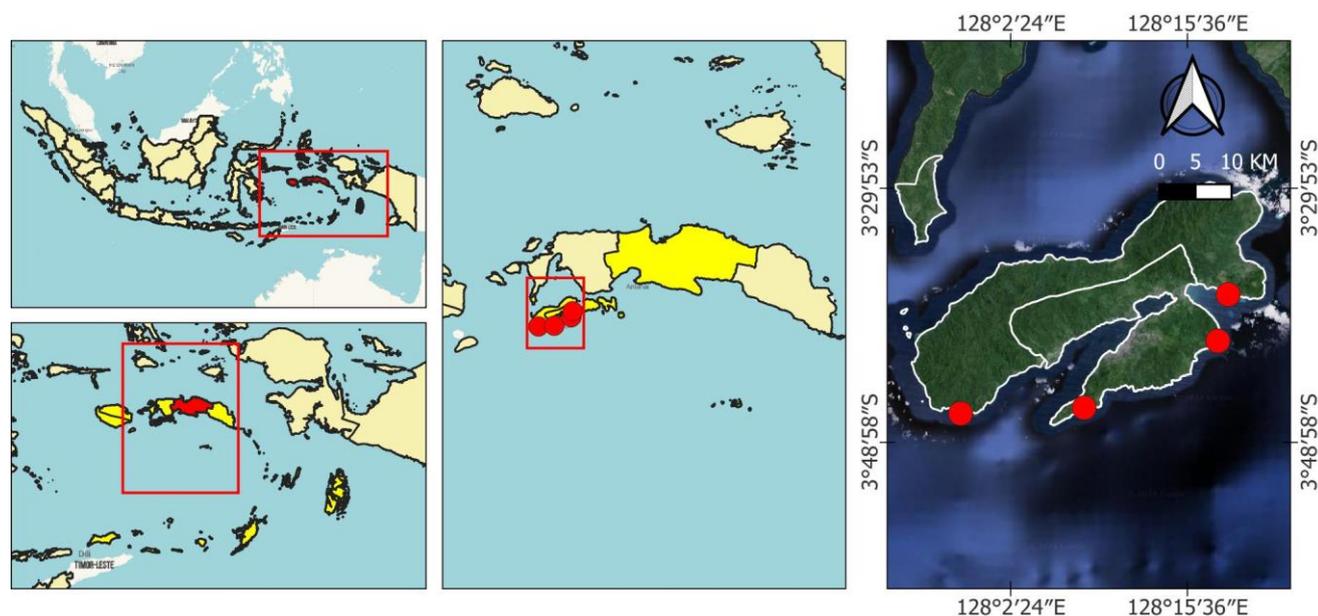


Figure 1. Study locations in Ambon Island, Maluku, Indonesia [Red dots indicate four locations]

Table 1. Geographical conditions of waters in this study in Ambon Island, Maluku, Indonesia

Location	Slope	Range (m)	Latitude	Longitude	Height	Coordinate point
Aer low	60.0000111 ⁰	1.107.00368	-3.7748585 ⁰	128.1321497 ⁰	7.1234675	3°46'40\"S, 128°07'55\"E
Suli	59.961602 ⁰	809.2938129	-3.6373316 ⁰	128.3181125 ⁰	-0.1887869	3°38'22\"S, 128°19'05\"E
Alang	44.996677 ⁰	531.3485977	-3.7816083 ⁰	127.9770405 ⁰	0.1014395	3°46'57\"S, 127°58'37\"E
Hutumuri	-	909.144487	-3.6873857 ⁰	128.2997294 ⁰	6,9827965	3°41'14\"S, 128°17'59\"E

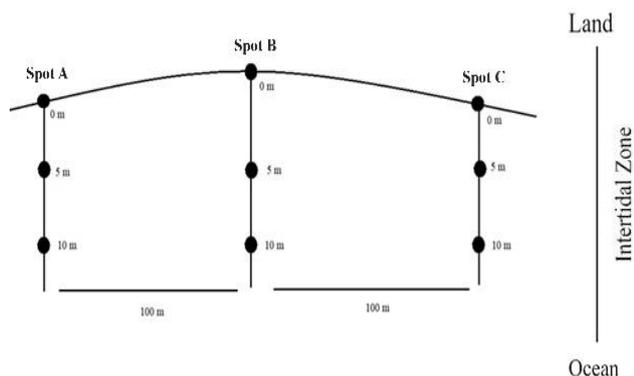


Figure 2. Line transect method

Procedures

Sample preparation

The locations to be explored were determined before commencing this study, and then physical and chemical environmental factors, including temperature, pH, salinity, and DO, were measured (Handayani et al. 2023). Figure 2 shows algae samples were collected during low tide using the line transect method. Those macroalgae found were stored in labeled plastic containers and transported to the laboratory for washing with running water, eliminating sand and dirt attached to the surface.

Sample identification

The sample images were captured using a Canon EOS 700D camera, followed by observing morphological characteristics such as color/thallus pigments, general thallus shape, blade shape, blade tip shape, and blade edge shape. Others included holdfast, main axis shape, holdfast shape, stipe, presence of ribs on the stipe, thallus branching shape, blade position, midrib, ramuli, phylloid, frond, phylloid shape, frond shape, receptacle (spore-bearing branch), and receptacle shape. Subsequently, the samples were preserved in a 10% formalin and water solution and identified by comparing observed characteristics with descriptions provided by AlgaBase (2023) and Gakken (1979).

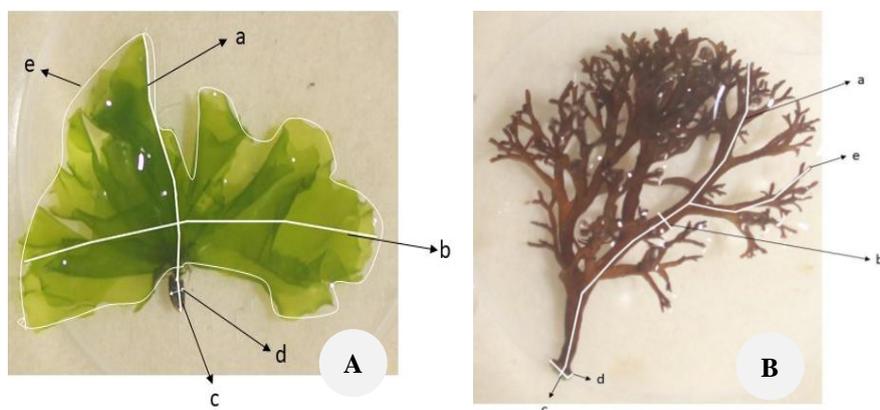


Figure 3. Morphometric visualization of macroalgae. A: a. thallus length; b. thallus width; c. holdfast length; d. holdfast width; e. phylloid width. Image B: a. thallus length; b. thallus width; c. holdfast length; d. holdfast width; e. branch length

Morphometric measurements

Morphometric measurements of thallus and holdfast length and width were conducted on all algae samples (Figure 3) for macroalgae resembling sheets, phylloid width and length were estimated, while those with a cylindrical shape were subjected to branch measurements. The overall length measurement covered the distance from the holdfast to the longest thallus tip. Furthermore, morphometric measurements were performed using the Raster image processing application.

Data analysis

The collected macroalgae exploration data were analyzed qualitatively through image interpretation and morphological characterization and quantitatively by calculating mean and standard deviations for measurements of physicochemical environmental factors. Subsequently, relationship analysis was conducted using Raster version 4.3.1, and the effective contribution standard error (SE) was estimated with the formula from Hadi (2004):

$$EC\%X_n = RC\%X_n \times R^2$$

RESULTS AND DISCUSSION

Physicochemical environmental factors

The measurements of physicochemical environmental factors showed variations in temperature, pH, salinity, and DO, as presented in Table 2. Macroalgae species thriving in the four study locations manifested adaptation ability towards the environment, suggesting that the physical and chemical factors were optimal. However, high temperatures could be a stress factor, affecting pigment color and macroalgae distribution across specific locations (Menaar et al. 2020; Takolander et al. 2017; Wernberg et al. 2016). Roleda and Hurd (2019) stated that an optimal temperature was crucial for macroalgae survival, regulating enzyme activity, chemical reaction rate constants, and nutrient uptake rates. Hyposaline or hypersaline conditions were found to influence the biochemistry and biodiversity of these organisms (Monteiro et al. 2021; AbouGabal et al. 2022).

Table 2. Data on physicochemical environmental factors in study sites of Ambon Island, Maluku, Indonesia

Location	Measurement results of physicochemical environmental factors				
	Temperature (°C)	pH	Salinity (‰)	DO (mg/l)	Substrate
Hutumuri (H)	30.05±0.041	8.34±0.005	32.00±0.082	8.00±0.0471	Sandy coral
Alang (A)	25.00±0.082	7.00±0.044	34.00±0.0471	6.00±0.0471	Sandy coral
Aer Low (AL)	29.50±0.368	7.53±0.042	35.00±0.0471	7.70±0.0943	Coral
Suli (S)	25.00±0.082	7.50±0.0471	31.00±0.0471	15.27±0.0420	Sandy coral and mud sand

Previous studies described ideal environmental conditions for macroalgae; for example, optimal pH for the genus *Gracilaria* was identified as 6.61, and an increase to 9.30 led to growth decline, while optimal salinity ranged from 20-50 ppt (Lee et al. 2019; Alves et al. 2021). The optimal pH and salinity for proper growth of the genus *Caulerpa* were 8.42-9.41 and 29.13-31.54 ppt, respectively (Sompong et al. 2020). Pereira et al. (2023) reported salinity as a determining factor for macroalgae distribution in a water body, with *Acanthophora spicifera* tolerating values between 25-40 PSU whereas 15 and 50 PSU salinity values induced biochemical changes such as color loss and biomass alterations. Average environmental factors for the genus *Porphyra* included temperature, pH, and salinity ranging from 25.36-27.5, 7.96-8.10, and 20.6-25.3 PSU, respectively (Pise et al. 2013). *Hypnea cervicornis* J. Agardh lives at an ideal salinity of 250/00 conditions and temperature 25°C (Ding et al. 2013). Environmental factors exceeding limits, such as high salinity concentrations, can inhibit photosynthesis, disrupting productivity, cell biochemical composition, and cell structure (Gani et al. 2019). Each species of macroalgae can live on ideal physicochemical factors but can survive in different conditions due to good adaptability.

The substrate was found to be a source of nutrients and a place for macroalgal growth to attach, significantly influencing the type of organism. Suli Beach consists of a substrate in the form of sandy coral and muddy sand, contributing to various types of macroalgae morphology. Coral rocks containing sediment are suitable for the growth of macroalgae because they have the ability to store organic and inorganic compounds without causing ecosystem harm to coral reefs (Guo et al. 2022; Widyartini et al. 2021; Rahardjanto et al. 2020). Some macroalgae species such as *Halimeda* and *Caulerpa* thrive on the substrate of mud, sand, and coral fragments, while *Padina*, *Sargassum*, and *Gracilaria* can be found on dead coral (Melsasail et al. 2018).

Whereas several studies show the types of macroalgae that live in various substrates, including Arsianti et al. (2020) reported that *S. polycystum* from Dompur Beach, Lombok Nusa Tenggara Barat thrives on coral reefs, dead coral, and volcanic rocks, with the ideal surface being coral reefs. Carreira-Flores et al. (2023) reported the presence of the *Sargassum* group, which is more commonly found on rocky substrates on the southwest coast of the Bay of Biscay. Kepel et al. (2019) reported the distribution of macroalgae on Mantehage Island, North Sulawesi, based on rocky substrates consisting of the species *Dictyosphaeria cavernosa*, *S. cristaeifolium*, *C. serrulata*,

C. sertularioides, *P. australis*, *H. opuntia*, *C. racemosa*; muddy sand substrate consisting of the species *Boergesenia Forbesii*, *C. crassa*; sandy substrate consisting of the species *G. salicornia*, *G. edulis*. Veeragurunathan et al. (2022) found that corals exposed to strong wave pressure had limited macroalgae species. In addition, the mixture of sand and mud causes a reduction in species diversity because the sediment that settles next to the sand interferes with sunlight absorption.

Macroalgae identification

Several interesting species, including *Dictyosphaeria versluisii*, *Sargassum polycystum*, *Galaxaura rugosa*, and *G. salicornia*, were identified during this study in Hutumuri and Suli Villages. *Gymnogongrus flabelliformis* and *Ceramium kondoi* were found on Aer Low and Alang coral substrates. *Boodlea coacta* was detected in Hutumuri and Alang, while *U. lactuca* and *P. australis* were found in Alang and Suli. *Amphiroa fragilissima*, *T. ornata*, and *C. racemosa* var. *peltata* were distributed across Hutumuri, Suli, and Alang (Table 4), while other species were present in only one location.

Morphologically, the *Caulerpa* genus consists of rhizoids, stolons, and assimilators (parts resembling a leaf) with a branch arrangement that characterizes each species (Belton et al. 2019; Wirawan et al. 2022). The assimilators differ depending on the species, with some being fan-shaped, spiral-shaped, or similar to grapes. Moreover, macroalgae belonging to sheet thallus included *U. lactuca*, *Porphyra crispata*, genus *Sargassum*, and genus *Padina*. The narrow sheet thallus group comprised *B. coacta*, *Bryopsis ryukyuensis*, *C. crassa*, *Enteromorpha prolifera*, *Dictyota bartayresiana*, and *Ectocarpus siliculosus*. The group with triangular thallus includes *T. ornata* and *H. opuntia*. Those classified as cylindrical thallus were *Galaxaura rugosa*, *Jania adherens*, *Gigartina affinis*, *Gymnogongrus flabelliformis*, *Hypnea cervicornis*, as well as the genera *Acanthophora*, *Amphiroa*, and *Gracilaria*. According to Kepel et al. (2020), the *Enteromorpha* genus possessed light green thallus shaped as hollow filaments resembling hair.

Meinita et al. (2021) and Kongkittayapun and Chirapart (2011) reported that *Gracilaria* belonged to Rhodophyta group. However, *G. salicornia* and *G. coronopifolia* are dark green to brown green and yellowish to brownish. The Chlorophyta group has a filamentous, sheet, and cylindrical thallus, primarily used in shallow waters to absorb sunlight. Phaeophyta features a fan-shaped thallus with sheets and contains radial, cylindrical concentric lines. Furthermore, the leaf morphology resembles a trumpet with serrated

edges, and thallus is similar to Cormophyta plants. Rhodophyta has strong holdfasts firmly anchored in the substrate with thallus some appear cylindrical, spiny, and bear intermittent branches, while others contain lime and are herbaceous (Erniati et al. 2023).

Moreover, 37 macroalgae species were identified, with 12, 7, 17, and 1 belonging to Ulvophyceae, Phaeophyceae, Florideophyceae, and Bangiophyceae classes. This number exceeded the 21 species reported by Litaay (2014) from Salobar Water, Hative Besar, Tantui, Halong, and Lateri, from Ambon Island, ordered as Rhodophyceae> Chlorophyceae> Phaeophyceae. Litaay et al. (2021) reported 22 species originating from Tantui, Hative Besar, and Alang, with a distribution of Rhodophyta> Phaeophyta> Chlorophyta. Previous results and this current study showed the prevalence of macroalgae from Rhodophyta class in Ambon Island waters. This observation was supported by Titlyanov et al. (2018), stating that red algae (Rhodophyta) constituted the largest group of macroalgae, with 4,000 identified species exceeding Chlorophyta and Phaeophyta. Kokabi et al. (2016) reported similar results on the east coast of Qeshm Island in the Persian Gulf, Iran, where Rhodophyta dominated but had a small biomass due to the small filamentous algae such as the genera *Jania*, *Hypnea*, *Gracilaria*, *Acanthophora*, and *Ceramium*.

Therefore, from highest to lowest, Macroalgae diversity observed in sequence included 25, 12, 8, and 7 species in the waters of Suli, Hutumuri, Alang, and Aer Low Villages, respectively (Table 3). These differences were influenced by substrate factors, where Suli waters contained more species due to muddy sand and sandy coral. Zulpikar and Handayani (2021) reported a similar result in the Mangaitan, Setuga, Padar, and Muntia Islands, attributing the high species biodiversity to soft and hard substrate presence. This current study showed that *A. fragilissima* adapted to the environment through attachment to other macroalgae, particularly *Caulerpa racemose* var. *peltata*, as a substitute for hard coral in Sungai Pulai, Johore (Harah et al. 2014).

This study found the genus *Caulerpa* in rock substrates in Alang, Hutumuri, and Suli villages. *Sargassum* has a wide habitat because it can be attached to sand substrates and corals. In contrast, *U. lactuta*, *D. versluisii*, *P. crispata* and *Amphiroa* spp. have specific substrates, namely hard substrates such as corals. *Caulerpa* types with rhizoid types were more developed on sand substrates or not compact rocks, such as gravel (Costa et al. 2001; de Carvalho et al. 2013). *Gracilaria salicornia* and *H. macrolaba* are the most common species found in sand habitats; this is also because the holdfast of *Halimeda* is round-type, while the genera *Padina* spp. and *S. polycystum* are very suitable for growing in rocky substrates because holdfast type attaches laterally to strong and stable substrates, filamentous algae such as *Chaetomorpha* spp. are very suitable on rocky substrates and form green "mats" in rocks (Zainee et al. 2019; de Maria César Ferreira et al. 2022). Genus *Porphyra* is a macroalgae with a narrow ecological niche only found in coral substrates (Meynard et al. 2019). Moreover, this study shows *C. crassa*, *U. lactuta*, *A.*

fragilissima, *A. misakiensis*, and *D. versluisii* grow on coral substrates; the genus *Sargassum* on coral and sand substrates in the Suli and Hutumuri area.

Macroalgae morphometric characteristics

Morphometric measurements of macroalgae in this study were conducted based on the species observed. Those resembling sheets, namely the genera *Padina* and *Ulva*, were evaluated for overall length, thallus width and length, holdfast length, and width, as well as phylloid width. The cylindrical types had additional characteristics, including phylloid length and branching. Additionally, macroalgae similar to higher plants, such as *Sargassum* and *Turbinaria*, were assessed for all morphometric characteristics (Table 5). The results showed that morphometric measurements differed among the same species in different environments. Examples of these variations were observed in *Boodlea coacta* (Dickie) G. Murray & De Toni 1889, *Dictyosphaeria versluisii* Weber Bosse 1905, *C. racemosa* var. *peltata*, *U. lactuca* Linnaeus 1753, *Padina australis* Hauck 1887, *Sargassum polycystum* C. Agardh 1824, *T. ornata* (Turner) J. Agardh 1848, and *Galaxaura rugosa* (J. Ellis & Solander) J.V. Lamouroux 1816. Other species including *Ceramium kondoi* Yendo 1920, *Amphiroa fragilissima* (Linnaeus) J.V.Lamouroux 1816, *Gracilaria salicornia* (C. Agardh) E.Y.Dawson 1954, and *Gymnogongrus flabelliformis* Harvey 1857 were used for monitoring the variations.

The study aligns with several studies, including by Díaz-Tapia et al. (2020), suggesting that morphometric analysis of macroalgae species produced diversity due to environmental influences; Santiañez and Trono (2013) reported morphotypes differences among *Sargassum* from the Philippine Islands of Alabat, namely *S. crassifolium* J. Agardh, *S. cristaefolium* Agardh, *S. kushimotoense* Yendo, *S. gracillimum* Reinbold, *S. myriocystum* J. Agardh, and *S. polycystum* C. Agardh. According to Yap-Dejeto et al. (2022), the morphological plasticity ability of *Sargassum* was very high due to environmental influences. Belton et al. (2019) stated the significance of morphology exploration due to the very high level of plasticity among the species *C. racemose* var. *peltata*. Moreover, the study conducted on macroalgae morphometrics by Estrada et al. (2020) showed morphometric variations in branching, assimilator height, distance between assimilators, ramulus diameter, and number of holdfasts in *C. racemose* at 13 aquatic locations. The same results were also found in the *C. racemosa* variation, namely, the overall length, length and width of the holdfast and branching were found in the Alang, Hutumuri, and Suli locations, while the length and width of the thallus and the length and width of the phylloid were found in the Hutumuri and Suli areas.

Neustupa and Nemcova (2020) reported morphometric variations in the segments and branches of the *Halimeda tuna* species. Verbruggen et al. (2005), Neustupa and Nemcova (2018), and Kase et al. (2019) further reported *H. opuntia* species with different morphological characteristics in terms of thallus segments due to variations in environmental factors. Moreover, Kim et al. (2022) reported that environmental adaptations impact the

size of *S. thunbergia*, showing the potential of morphometrics to provide insights into environmental quality. These studies can serve as a reference that environmental factors can affect the morphological and morphometric characteristics of a macroalgae species. In comparison, a brief morphological description of macroalgae from Ambon Island is presented in Table 4. Morphometric measurements of macroalgae from Ambon Island are presented in Table 5.

Relationship between physicochemical and morphometric factors

Physical and chemical environmental factors have a relationship with the morphometric characteristics of macroalgae but do not have a uniform impact on all morphometric characteristics. This is indicated by the negative value in the Adjusted R-squared, which means that the physical and chemical environmental factors have a negative relationship with several morphometric characteristics with a significance level of $p < 0.05$ (Table 6). Meanwhile, there is also a positive relationship between physical and chemical environmental factors and several morphometric characteristics with a significance level of $p < 0.05$ (Table 6).

The relationship between physical and chemical environmental factors to these characteristics was recorded respectively as Holdfast Length > Holdfast Width > Full Length > Thallus Width > Thallus Length in Hutumuri, Holdfast Length > Thallus Width > Thallus Length > Full Length > Holdfast Width in Alang, Thallus Width > Full Length > Thallus Length > Holdfast Width > Holdfast Length in Aer Low, and Holdfast Width > Thallus Length > Full Length > Holdfast Length > Thallus Width in Suli (Table 6). Some research aligns with the study's results; for example, Tiwari and Troy (2015) reported a relationship between environmental factors, such as temperature, radiation, nutrition, water movement, and thallus regeneration capacity during cultivation. Erlania and Radiarta (2015) found that macroalgae biomass and yield of *Kappaphycus alvarezii* var. Tambalang and Maumere, *K. striatum*, and *E. denticulatum* were related to turbidity, nutrition, and seawater temperature. Roleda and Hurd (2019) described the abiotic factors influencing macroalgae productivity. Seawater temperature plays a significant role in determining morphometric characteristics of *E. cava* (Laminariales, Phaeophyta) in two distinct locations (Serisawa et al. 2002).

Three species *Halimeda tuna*, *H. opuntia*, and *Dictyota* sp. have diverse morphometric sizes in four locations featuring different light conditions, temperatures, nutrients, and hydrodynamics (Yñiguez et al. 2010). Furthermore, Sissini et al. (2022) reported coralline red algae thriving in ecoregions with tropical and warm climates, where temperature, nutrient levels, and water current speed facilitated growth and development. These factors included the effect of seawater movement on the DO diffusion process and the impact of light absorption on the photosynthesis rate. Furthermore, temperature greatly affects enzyme activity, metabolic reaction rates, and macroalgae nutrient diffusion. An increase in CO₂

concentration increases the activity of the enzyme nitrate reductase, while low salinity concentration positively influences nutrient absorption.

Nevertheless, many of these relationships had negative values in this study, showing a lack of correlation with physical and chemical environmental factors. A similar result by Lemesle et al. (2023) stated that environmental factors such as solar radiation had a negative relationship with the location of macroalgae deposits, while air temperature and wave size showed a positive relationship on Luc-sur-Mer Beach in Normandy, France. This analysis of Ambon Island waters would be a beneficial resource for cultivating potential macroalgae species in the future.

The relationship of physicochemical and environmental factors to the morphometrics of the same species at different locations can only be explained by a few species. This is because not all species live in these four locations. As for species that can be compared morphometrically to the relationship of physical, chemical, and environmental factors, only a few of them include *Boodlea coacta* (Dickie) G. Murray & De Toni 1889, *Dictyosphaeria versluysii* Weber Bosse 1905, *Caulerpa racemosa* var. *peltata*, *Ulva lactuca* Linnaeus 1753, *Padina australis* Hauck 1887, *Sargassum polycystum* C. Agardh 1824, *Turbinaria ornata* (Turner) J. Agardh 1848, *Galaxaura rugosa* (J.Ellis & Solander) J.V. Lamouroux 1816, *Ceramium kondoi* Yendo 1920, *Amphiroa fragilissima* (Linnaeus) J.V. Lamouroux 1816, *Gracilaria salicornia* (C.Agardh) E.Y. Dawson 1954, *Gymnogongrus flabelliformis* Harvey 1857 (Table 5).

The results showed differences in morphometric size in the same macroalgae species due to different physicochemical factors (Table 5 and Table 6). According to Karsten (2012), the same macroalgae species but growing in different salinity conditions can show different tolerances because salinity is one factor affecting the growth of fine grains and the distribution of macroalgae. Different physicochemical and environmental factors at the location of Aer Low and Alang affect the morphometrics of both types of macroalgae, namely *Ceramium kondoi* Yendo 1920 and *Gymnogongrus flabelliformis* Harvey 1857 (See in Table 2). The results showed variations in the morphometric size of the species *Ceramium kondoi* Yendo 1920 living at the location of Aer Low > Alang, in contrast to the morphometric size of the species *Gymnogongrus flabelliformis* Harvey 1857 living at the location of Alang > Aer Low. Some macroalgae species such as *Dictyosphaeria versluysii* Weber Bosse 1905, *Padina australis* Hauck 1887, *Sargassum polycystum* C. Agardh 1824, *Turbinaria ornata* (Turner) J. Agardh 1848, *Galaxaura rugosa* (J.Ellis & Solander) J.V.Lamouroux 1816, and *Gracilaria salicornia* (C.Agardh) E.Y. Dawson 1954 have morphometric variations, namely morphometric at the location of Suli > Hutumuri. Especially for *Sargassum* types, it is reported that high salinity and temperature affect the growth of *Sargassum* (Li et al. 2019; Graba-Landry et al. 2020).

Table 3. Composition of macroalgae taxa found in the study locations in Ambon Island, Maluku, Indonesia

Class	Ordo	Family	Genus	Species	Data collection locations				Total species
					H	A	AL	S	
Ulvophyceae	Cladophorales	Boodleaceae	Boodlea	<i>Boodlea coacta</i> (Dickie) G.Murray & De Toni 1889	+	+	-	-	12
		Siphonocladaceae	Boergesenia	<i>Boergesenia forbesii</i> (Harvey) Feldmann 1938	-	-	-	+	
		Cladophoraceae	Chaetomorpha	<i>Chaetomorpha crassa</i> f. <i>genuina</i> Schiffner nom. inval. 1938	-	-	+	-	
		Siphonocladaceae	Dictyosphaeria	<i>Dictyosphaeria versluysii</i> Weber Bosse 1905	+	-	-	+	
	Bryopsidales	Bryopsidaceae	Bryopsis	<i>Dictyosphaeria cavernosa</i> (Forsskål) Børgesen 1932	-	-	-	+	
				<i>Bryopsis ryukyuensis</i> Yamada 1934	-	-	+	-	
		Halimedaceae	Halimeda	<i>Halimeda opuntia</i> (Linnaeus) J.V.Lamouroux 1816	-	-	-	+	
				<i>Caulerpa racemosa</i> var. <i>peltata</i>	+	+	-	+	
		Caulerpaceae	Caulerpa	<i>Caulerpa sertularioides</i> f. <i>farlowii</i> (Weber Bosse) Børgesen 1907	-	-	-	+	
				<i>Caulerpa serrulata</i> (Forsskål) J.Agardh 1837	-	-	-	+	
Ulvales	Ulvaceae	Enteromorpha	<i>Enteromorpha prolifera</i> (O.F.Müller) J.Agardh, 1883	-	-	-	+		
Phaeophyceae	Dictyotales	Dictyotaceae	Ulva	<i>Ulva lactuca</i> Linnaeus 1753	-	-	+	+	
			Dictyota	<i>Dictyota bartayresiana</i> J.V.Lamouroux 1809	-	-	-	+	
			Padina	<i>Padina australis</i> Hauck 1887	-	+	-	+	
	Ectocarpales	Ectocarpaceae	Ectocarpus	<i>Padina crassa</i> Yamada 1931	+	-	-	-	
				<i>Ectocarpus siliculosus</i> (Dillwyn) Lyngbye, 1819	-	-	+	-	
	Fucales	Sargassaceae	Sargassum	<i>Sargassum crassifolium</i> J.Agardh 1848	-	-	-	+	
				<i>Sargassum polycystum</i> C.Agardh 1824	+	-	-	+	
				<i>Turbinaria ornata</i> (Turner) J.Agardh 1848	+	+	-	+	
				<i>Turbinaria ornata</i> (Turner) J.Agardh 1848	+	-	-	+	
	Florideophyceae	Nemaliales	Galaxauraceae	Galaxaura	<i>Galaxaura rugosa</i> (J.Ellis & Solander) J.V.Lamouroux 1816	+	-	-	+
Ceramiales		Rhodomelaceae	Acanthophora	<i>Acanthophora spicifera</i> (M.Vahl) Børgesen 1910	+	-	-	-	
				<i>Acanthophora muscoides</i> (Linnaeus) Bory 1828	-	-	-	+	
				<i>Acanthophora dendroides</i> Harvey 1855	-	-	-	+	
Corallinales		Ceramiaceae	Ceramium	<i>Ceramium kondoi</i> Yendo 1920	-	+	+	-	
		Lithophyllaceae	Amphiroa	<i>Amphiroa misakiensis</i> Yendo 1902	+	-	-	-	
Gracilariales		Gracilariaceae	Gracilaria	<i>Amphiroa fragilissima</i> (Linnaeus) J.V.Lamouroux 1816	+	+	-	+	
				<i>Jania adherens</i> Lamouroux 1816	-	+	-	-	
				<i>Gracilaria arcuata</i> Zanardini 1858	-	-	-	+	
				<i>Gracilaria coronopifolia</i> J.Agardh 1852	-	-	-	+	
Gigartinales	Gigartinaceae	Gigartina	<i>Gracilaria lichenoides</i> f. <i>coronopifolia</i>	-	-	-	+		
			<i>Gracilaria salicornia</i> (C.Agardh) E.Y.Dawson 1954	+	-	-	+		
			<i>Gigartina affinis</i> Harvey 1860	-	-	-	+		
			<i>Gymnogongrus flabelliformis</i> Harvey 1857	-	+	+	-		
			<i>Hypnea cervicornis</i> J.Agardh 1851	-	-	-	+		
Halymeniales	Halymeniaceae	Halymenia	<i>Halymenia floresii</i> (Clemente) C.Agardh 1817	-	-	-	+		
			<i>Plocamium ovicorne</i> i	-	-	-	+		
Bangiophyceae	Bangiales	Bangiaceae	Porphyra	<i>Porphyra crispata</i> Kjellman 1897	-	-	+	-	
Total					12	8	7	25	

Table 4. Identification of macroalgae from Ambon Island, Maluku, Indonesia

Species and morphology	Specimen		
Ulvophyceae			
<i>Boodlea coacta</i> Thallus is green, smooth, small, and cylindrical. It attaches to dead coral to form a carpet.		<i>Bryopsis ryukyuensis</i> Thallus is dark green, has a smooth cylinder form, is dense at the base, and resides in coral habitats.	
<i>Boergesenia forbesii</i> Thallus is dark green, soft, cylindrical, enlarged from the middle to the tip, and arranged as a floret, inhabiting coral rocks.		<i>Halimeda opuntia</i> The light green thallus consists of segments similar to small triangles and lime. It is hard, rigid, overlapping each other, and found in sand habitats.	
<i>Chaetomorpha crassa</i> f. <i>genuina</i> Thallus is light green, slender, cylindrical, and long, forming a carpet on dead coral.		<i>Caulerpa racemosa</i> var. <i>peltate</i> Thallus is light green, in the form of an elongated stolon, with rhizoids, and has an assimilator (similar to a phylloid) with a button-shaped protrusion. It resides in coral and sandy coral habitats.	
<i>Dictyosphaeria versluisii</i> Thallus is dark green, the surface is hard with small pores, and it attaches to coral rocks.		<i>Caulerpa sertularioides</i> f. <i>farlowii</i> Thallus is light green, in the form of an elongated stolon, contains rhizoids, and has a fan-shaped assimilator (similar to a phylloid). It is found in coral habitats.	
<i>Dictyosphaeria cavernosa</i> Thallus is light green, with small protrusions on the surface, and attaches to rocks.		<i>Caulerpa serrulata</i> Thallus is light green in the form of an elongated stolon and contains rhizoids. It also has a spiral-shaped assimilator (similar to a phylloid) and resides in coral habitats.	

Enteromorpha prolifera

Thallus is light green, the strands from the middle to the tip are rolled up in a spiral shape, and it thrives in coral habitats.

*Ulva lactuca*

Thallus is light green and in flat sheets arranged in a fan shape. It is found in coral habitats.

**Phaeophyceae***Dictyota**bartayresiana*

Thallus is brown, with a flat and narrow sheet, and a slit at the tip.

*Padina crassa*

Thallus is brown and in the form of thin as well as easily tearable sheets resembling a fan. It has a short stipe, with short hair around the holdfast, and inhabits coral habitats.

*Padina australis*

Thallus is brown and in the form of thin as well as easily tearable sheets. It has a long stipe with long hair around the holdfast and inhabits coral habitats.

*Ectocarpus siliculosus*

Thallus is brown, in the form of smooth strands, and resides in coral rock habitats.

*Sargassum crassifolium*

Thallus is brown, with a smooth stipe (organ similar to stem) and a thick, oval-shaped phylloid (organ resembling leaf). The edges of the phylloid are serrated, the tip is pointed, and the vesicles are round, as commonly found in coral habitats.

*Sargassum polycystum*

Thallus is brown, with a rough, blunt protrusion on the stipe (organ resembling a rod). The phylloid is oval to elliptical, with serrated edges and a pointed tip. It also has thin, round vesicles found in sand and coral habitats.

*Turbinaria ornata*

The brown thallus comprises triangular phylloids and has a holdfast with long branches. It resides in coral habitats.

**Florideophyceae***Galaxaura rugosa*

Thallus is red, very hard, segmented, branched, and thrives in coral habitats.



Acanthophora spicifera

Thallus is reddish-brown and cylindrical. It has a surface covered with blunt protrusions and lives on coral.

*Acanthophora muscoides*

Thallus is reddish-brown, with branches at the tip and occasionally in the middle. The surface has blunt protrusions, and it thrives on muddy sand.

*Acanthophora dendroides*

Thallus is reddish-brown, with few branches and blunt protrusions on the surface. Its habitat is muddy sand.

*Ceramium kondoi*

Thallus is dark red in fine strands arranged as a carpet on the surface of coral rocks.

*Amphiroa misakiensis*

Thallus is dark red, with a hard tube, and lives in coral habitats.

*Amphiroa fragilissima*

Thallus is blackish-red and slightly stiff while it inhabits coral habitat.

*Jania adherens*

Thallus is dark red, slightly stiff, and resides in coral habitats.

*Gracilaria arcuata*

Thallus is green, in the form of stolons, with soft branches along its length, and thrives in muddy sand habitat.

*Gracilaria coronopifolia*

Thallus is light green, in the form of stolons, and has soft branches. Branching converging towards the base, repetitive, and irregularly alternating. It is found in muddy sand habitats.

*Gracilaria lichenoides f. coronopifolia*

The red thallus is in the form of stolons with soft branches. Branching converging towards the base, repetitive, and irregularly alternating. It resides in muddy sand habitats.

*Gracilaria salicornia*

Thallus is yellowish-green, cylindrical, and smooth with septa. The branches are cylindrical, with the tip enlarged and rounded and the base slightly smaller. It has fine hair follicles on the septa and is found in rock and sandy habitats.

*Gigartina affinis*

Thallus is yellowish-green, cylindrical, and intertwined with one another. The surface is smooth but features many branches and is found in sand habitats.



Gymnogongrus flabelliformis

Thallus is red and cylindrical, with soft branches on the tip, and resides in coral habitats.

*Hypnea cervicornis*

Thallus is green, in a small cylinder form, with irregular branches along it, and is found in muddy sand habitats.

*Halymenia floresii*

Thallus is dark red, flat, soft, with many branches, and often resides on coral surfaces.

*Plocamium ovicorne*

Thallus is bright red, in a small cylinder form, with small branches along its length, and is often found in coral habitats.

**Bangiophyceae***Porphyra crispata*

Thallus is brown in the form of sheets overlapping at the base and thrives on coral surfaces.



Borburema et al. (2021) also explain various studies on high temperatures that high seawater temperatures cause growth decline; high temperatures favor the evaporation rate, thus affecting the photosynthesis of macroalgae (Lamote et al. 2012). Moreover, temperature can affect photosynthesis and other metabolic pathways of seaweed since enzymatic activity depends on temperature (Lalegerie et al. 2015). Furthermore, according to Eggert (2012), seaweed responds to temperature in three ways: genetic adaptation to constant living ambient temperature, phenotypic acclimatization, or short-term physiological regulation in response to temporal temperature shocks.

High pH values cause the growth response of coralline macroalgae thallus to slow down (Cornwall et al. 2013). This is in line with the results of research that the morphometric type of Coralline macroalgae, namely *Galaxaura rugosa* (J.Ellis & Solander) J.V.Lamouroux 1816, which grows in locations with high seawater pH values, namely Hutumuri<Suli. Furthermore, Ji et al. (2016) explained that fluctuations in the pH of seawater against macroalgae specific to certain types and regions depend on their microhabitat. In general, it can be explained that macroalgae with the same species can have morphometric characteristics such as the full length of the whole body, length and width of the thallus, and branching, length, and width of holdfast have different characteristics due to exposure to different physicochemical environmental factors, this depends on the ability of the species to adapt and survive in these conditions. However, the species' distinctive features remain a species identity.

Although this study did not investigate the impact of biotic factors on morphometric characteristics, it is important to note that these factors play a significant role. Grazing pressure is one of them to be an influential biotic factor (Flores et al. 2015; Sampaio et al. 2017). There is a symbiotic relationship between macroalgae and coral reefs (Fulton et al. 2019; Monteil et al. 2020; Sura et al. 2021), as well as releasing exudates from macroalgae containing toxic substances to deter herbivores, larvae, or other macroalgae (Fong et al. 2019; Lenzo et al. 2023; Pezzolesi et al. 2021; Alvarez-Hernandez et al. 2019) are also important factors. Although these were not part of the scope of this study, they form the basis for future research.

Table 5. Morphometric measurements of macroalgae from Ambon Island, Maluku, Indonesia

Species	Location	Full length (μm)	Thallus width (μm)	Thallus length (μm)	Holdfast length (μm)	Holdfast width (μm)	Phylloid length (μm)	Phylloid width (μm)	Branching (μm)
<i>Boodlea coacta</i> (Dickie) G.Murray & De Toni 1889	Hutumuri	9736.41	6149.46	5460.79	3743.78	3546.51	nm	nm	nm
	Alang	7171.04	12632.72	7171.04	nm	nm	nm	nm	nm
<i>Boergesenia forbesii</i> (Harvey) Feldmann 1938	Suli	13755.52	5151.20	10041.24	2283.99	3272.16	nm	nm	nm
<i>Chaetomorpha crassa</i> f. <i>genuina</i> Schiffner nom. inval. 1938	Aer Low	936407.47	94861.33	930824.99	6481.55	7486.90	nm	nm	nm
<i>Dictyosphaeria versluysii</i> Weber Bosse 1905	Hutumuri	68146.38	14787.12	21962.15	19447.93	11555.98	nm	nm	nm
	Suli	93126.14	25852.37	29733.09	22684.46	24017.56	nm	nm	nm
<i>Dictyosphaeria cavernosa</i> (Forsskål) Børgesen 1932	Suli	105950.66	19922.60	27463.64	29835.84	29152.50	nm	nm	nm
<i>Bryopsis ryukyuensis</i> Yamada 1934	Aer low	918464.54	1090175.42	909152.12	4783.56	8128.96	nm	nm	nm
<i>Halimeda opuntia</i> (Linnaeus) J.V.Lamouroux 1816	Suli	143162.78	47485.22	139580.40	4144.77	5189.38	3462.53	2548.45	9867.78
<i>Caulerpa racemosa</i> var. <i>peltata</i>	Hutumuri	112003.38	1178.47	103817.97	6320.31	1131.33	5503.34	6637.33	32938.71
	Alang	798707.75	nm	nm	54038.35	5099.02	nm	nm	258489.76
	Suli	108497.98	1054.386	133074.73	11156.85	400.70	2567.33	2457.82	27221.70
<i>Caulerpa sertularioides</i> f. <i>farlowii</i> (Weber Bosse) Børgesen 1907	Suli	168732.99	1647.89	138378.78	47768.47	3134.13	25584.18	7603.53	49224.02
<i>Caulerpa serrulata</i> (Forsskål) J.Agardh 1837	Suli	176784.28	2353.99	169050.11	53367.57	3696.30	44061.36	41615.36	79621.75
<i>Enteromorpha prolifera</i> (O.F.Müller) J.Agardh, 1883	Suli	154202.41	1391.51	138980.21	13681.47	1447.77	nm	nm	nm
<i>Ulva lactuca</i> Linnaeus 1753	Alang	26523.25	40718.61	23690.60	3274.16	1730.05	nm	nm	nm
	Suli	30647.53	31189.60	28786.16	1710.689	842.76	nm	126063.77	
<i>Dictyota bartayresiana</i> J.V.Lamouroux 1809	Suli	42542.38	4491.29	33131.57	9320.41	5820.46	nm	nm	23786.00
<i>Padina crassa</i> Yamada 1931	Hutumuri	42502.53	45359.00	33460.45	8977.23	6529.90	nm	171422.57	nm
<i>Padina australis</i> Hauck 1887	Alang	25625.91	39591.63	23704.65	1534.36	3444.44	nm	113801.23	nm
	Suli	47767.66	50412.26	43435.26	4348.185	3974.33	nm	254767.04	nm
<i>Ectocarpus siliculosus</i> (Dillwyn) Lyngbye, 1819	Aer Low	49017.45	39935.90	46236.29	2773.62	3981.31	nm	nm	nm
<i>Sargassum crassifolium</i> J.Agardh 1848	Suli	121191.80	204196.10	111728.69	9338.13	11216.26	15887.21	9349.693	24043.48
<i>Sargassum polycystum</i> C.Agardh 1824	Hutumuri	33177.30	7919.85	27247.37	5424.43	361.55	nm	nm	6252.89
	Suli	77375.41	161429.50	72993.51	2593.91	5694.04	29799.37	8633.94	nm
<i>Turbinaria ornata</i> (Turner) J.Agardh 1848	Hutumuri	155015.41	55887.93	109556.75	54828.82	25403.09	22210.81	25216.40	nm
	Alang	1490756.02	1628562.98	694767.40	814102.59	40529.80	293265.37	480859.96	475697.84
	Suli	343735.44	96526.12	273656.71	63194.31	50478.49	20117.89	35947.33	47352.73
<i>Galaxaura rugosa</i> (J.Ellis & Solander) J.V.Lamouroux 1816	Hutumuri	16454.87	631.04	12826.68	511.95	882.55	nm	nm	8363.09
	Suli	26910.89	910.97	25750.56	954.67	1874.619	nm	nm	6031.73
<i>Acanthophora spicifera</i> (M.Vahl) Børgesen 1910	Hutumuri	36598.28	3826.96	34805.62	2009.35	1293.25	nm	nm	26704.71
<i>Acanthophora muscooides</i> (Linnaeus) Bory 1828	Suli	98297.9	5944.31	31663.96	3032.72	2969.34	nm	nm	19892.2
<i>Acanthophora dendroides</i> Harvey 1855	Suli	104731.26	5186.44	35367.62	7966.09	4752.01	nm	nm	15494.36
<i>Ceramium kondoi</i> Yendo 1920	Alang	17835.89	183.03	18519.44	1112.03	1026.09	nm	nm	1690.72
	Aer Low	46793.98	444.94	44799.22	1883.28	2717.58	nm	nm	40594.07
<i>Amphiroa misakiensis</i> Yendo 1902	Hutumuri	21695.81	572.52	20545.60	1296.72	1807.04	nm	nm	13202.54

<i>Amphiroa fragilissima</i> (Linnaeus) J.V.Lamouroux 1816	Hutumuri	22728.89	270.02	15110.94	1338.93	4004.69	nm	nm	8396.50
	Alang	49348.83	578.17	44449.05	2009.16	2008.36	nm	nm	5120.76
	Suli	15579.38	259.85	16058.92	2804.71	5208.27	nm	nm	6282.28
<i>Jania adherens</i> Lamouroux 1816	Alang	15268.29	13426.20	9847.57	12610.12	nm	2133.45	nm	1404.42
<i>Gracilaria arcuata</i> Zanardini 1858	Suli	106944.72	127239.57	17362.60	91515.27	3279.65	nm	nm	36810.56
<i>Gracilaria coronopifolia</i> J.Agardh 1852	Suli	203235.21	1593.82	18246.42	1321.01	879.96	nm	nm	59527.59
<i>Gracilaria lichenoides</i> f. <i>coronopifolia</i> (J.Agardh) V.May 1948	Suli	87531.24	1813.62	38609.70	1153.74	1449.07	nm	nm	46242.04
<i>Gracilaria salicornia</i> (C.Agardh) E.Y.Dawson 1954	Hutumuri	47877.46	2708.34	35986.25	4520.80	7722.54	nm	nm	18968.72
	Suli	57164	2941.67	21693.07	4115.87	2715.93	nm	nm	22337.72
<i>Gigartina affinis</i> Harvey 1860	Suli	72084.18	1182.14	10020.24	nm	nm	nm	nm	4943.35
<i>Gymnogongrus flabelliformis</i> Harvey 1857	Alang	50175.87	1578.09	48420.01	1469.69	3205.48	nm	nm	36509.41
	Aer Low	43239.89	1546.19	38713.05	3369.45	4564.10	nm	nm	13594.75
<i>Hypnea cervicornis</i> J.Agardh 1851	Suli	176147.04	1211.36	75683.39	742.97	495.66	nm	nm	63404.38
<i>Halymenia floresii</i> (Clemente) C.Agardh 1817	Suli	198836.27	10875.1	189415.06	9301.89	26223.50	nm	nm	nm
<i>Plocamium ovicorne</i> Okamura 1896	Suli	20071.21	863.77	18094.12	1828.40	1446.35	nm	nm	5993.23
<i>Porphyra crispata</i> Kjellman 1897	Aer Low	59926.31	56732.72	34063.60	2602.73	3293.75	nm	285086.93	nm

Note. Nm: not measured

Table 6. The relationship between physicochemical environmental factors to macroalgae morphometric characteristics in study sites of Ambon Island, Maluku, Indonesia

Morphometric characteristics	Multiple R-Squared	Adjusted R-Squared	F-value	p-value (p < 0.05)	Effective contribution
Hutumuri					
Full length	0.57	0.2833	1.988	0.022 ^(*)	28.33
Thallus width	0.4801	0.1336	1.385	0.034 ^(*)	13.36
Thallus length	0.1749	0.009875	1.06	0.040 ^(*)	0.9875
Holdfast length	0.7111	0.5185	3.692	0.050 ^(*)	51.85
Holdfast width	0.6161	0.3601	2.407	0.016 ^(*)	36.01
Alang					
Length	0.5688	0.2239	1.649	0.029 ^(*)	22.39
Thallus Width	0.6809	0.4256	2.667	0.015 ^(*)	42.56
Thallus Length	0.671	0.4077	2.549	0.016 ^(*)	40.77
Holdfast Length	0.6922	0.446	2.811	0.014 ^(*)	44.6
Holdfast Width	0.3802	-0.1156	0.7669	0.018 ^(*)	-11.56
Aer Low					
Length	0.7623	-0.1883	0.8019	0.037 ^(*)	-18.83
Thallus Width	0.9932	0.9661	36.61	0.013 ^(*)	96.61
Thallus Length	0.76	-0.1999	0.7918	0.016 ^(*)	-19.99
Holdfast Length	0.5861	-1.069	0.3541	0.032 ^(*)	-106.9
Holdfast Width	0.7117	-0.4417	0.617	0.028 ^(*)	-44.17
Suli					
Length	0.1939	0.03273	1.203	0.030 ^(*)	3.273
Thallus Width	0.1336	-0.03965	0.7712	0.050 ^(*)	-3.965
Thallus Length	0.671	0.4077	2.549	0.023 ^(*)	40.77
Holdfast Length	0.01578	-0.1811	0.08016	0.018 ^(*)	-18.11
Holdfast Width	0.9241	0.9089	60.87	0.006 ^(*)	90.89

In conclusion, this study identified 52 individuals from 37 species of macroalgae distributed across the coastal waters of Ambon Island, with various morphological and morphometric characteristics. Additionally, the physicochemical parameters of seawater, including temperature, salinity, pH, and DO, had significant simultaneous relationships with total length, thallus width, thallus length, holdfast length, and holdfast width, some being positive while others were negative. Other researchers have not previously reported findings on morphological and morphometric analysis of macroalgae from the island of Ambon. Therefore, current research recommends that future research focus on exploring macroalgae species on other islands in Maluku Province, utilizing macroalgae as raw materials for food, industry, and medicine, which will generate additional economic value. Therefore, it will increase macroalgae products into marine natural products and increase the sustainability and conservation of macroalgae typical of Maluku Province. Several types of macroalgae from Ambon island from the genera *Hypnea*, *Halymenia*, *Gymnogongrus*, *Gracilaria*, *Caulerpa*, and *Dictyosphaeria* have the potential to be studied and utilized. This is based on several studies that the use of *Saccharina japonica*, *Ulva rigida*, and *Porphyra dioica* as ingredients enriches the taste of chocolate in Portuguese (Salgado et al. 2023); *Laminaria* sp; *Sargassum muticum* and *Undaria pinnatifida* are sources of iodine (Badocco et al. 2017); *Gracilaria* sp. as artificial nori (Sari et al. 2019); *Sargassum polycystum*, *Turbinaria ornata* and *Padina boryana* are the sources of fucoidan, laminarin and alginate (Fauzief et al. 2023); Gelidiaceae,

Gracilariaceae, Gelidiellaceae and Pterocladaceae are groups of red macroalgae that are sources of alginate and carrageenan (Lee et al. 2017). Implications of the study's findings for conserving and cultivating macroalgae in Ambon Island are habitat maintenance (Swan et al. 2016), Reef to Ridge (R2R) (Vieira et al. 2021), while cultivation of macroalgae through fragmentation of talus or stolon (Moreira et al. 2022).

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REFERENCES

- AbouGabal AA, Khaled AA, Aboul-Ela HM, Aly HM, Diab MH, Shalaby OK. 2022. Marine macroalgal biodiversity, spatial study for the Egyptian Mediterranean Sea, Alexandria Coast. *Thalassas: Intl J Mar Sci* 38 (1): 639-646. DOI: 10.1007/s41208-021-00370-9.
- Afreen AB, Rasool F, Fatima M. 2023. Bioactive properties of brown seaweed, *Sargassum wightii* and its nutritional, therapeutic potential and health benefits: A review. *J Environ Biol* 4 (4): 146-158. DOI: 10.22438/jeb/44/2/MRN-5081.
- AlgaBase. 2023. Listing the World's Algae. <https://www.algaebase.org/>.

- Alves JDP, Junior APB, Henry-Silva GG. 2021. Salinity tolerance of macroalgae gracilaria birdiae. *Cienc Rural* 51 (1): 1-7. DOI: 10.1590/0103-8478cr20190958.
- Alvarez-Hernandez S, Lozano-Ramirez C, Rodriguez-Palacio M. 2019. View of influence of the implementation. *Ann Res Rev Biol* 33 (1): 1-9. DOI: 10.9734/ARRB/2019/v33i130113.
- Arias A, Feijoo G, & Moreira MT. 2022. Macroalgae biorefineries as a sustainable resource in the extraction of value-added compounds. *Algal Res* 69: 102954. DOI: 10.1016/j.algal.2022.102954.
- Arsianti A, Bahtiar A, Wangsaputra VK, Azizah NN, Fachri W, Nadapdap LD, Fajrin AM, Tanimoto H, Kakiuchi K. 2020. Phytochemical composition and evaluation of marine algal *Sargassum polycystum* for antioxidant activity and in vitro cytotoxicity on hela cells. *Pharmacognosy J* 12 (1): 88-94. DOI: 10.5530/pj.2020.12.14.
- Badocco D, Romanini F, di Marco V, Mondin A, Pastore P. 2017. Formation of volatile iodine compounds under hot concentrated acid conditions (nitric acid or aqua regia) and in diluted acid solutions with or without thiocyanate. *Polyhedron* 122: 25-28. DOI: 10.1016/j.poly.2016.10.015.
- Barbot YN, Al-Ghaili H, Benz R. 2016. A review on the valorization of macroalgal wastes for biomethane production. *Mar Drugs* 16 (6): 66-117. DOI: 10.3390/md14060120.
- Belton GS, Draisma SGA, van Reine WFP, Huisman JM, Gurgel CFDA. 2019. A taxonomic reassessment of *Caulerpa* (Chlorophyta, Caulerpaceae) in southern Australia, based on tufA and rbcL sequence data. *Phycologia* 58 (3): 234-253. DOI: 10.1080/00318884.2018.1542851.
- Borburema HDDS, Lima RPD, Miranda GECD. 2021. Effects of ocean warming, eutrophication and salinity variations on the growth of habitat-forming macroalgae in estuarine environments. *Acta Bot Brasilica* 34: 662-672. DOI: 10.1590/0102-33062020abb0303.
- Carreira-Flores D, Rubal M, Moreira J, Guerrero-Mesenguer L, Gomes PT, Veiga P. 2023. Recent changes on the abundance and distribution of non-indigenous macroalgae along the southwest coast of the Bay of Biscay. *Aquat Bot* 189: 103685. DOI: 10.1016/j.aquabot.2023.103685.
- Cornwall CE, Hepburn CD, McGraw CM, Currie KI, Pilditch CA, Hunter KA, Boyd PW, Hurd CL. 2013. Diurnal fluctuations in seawater pH influence the response of a calcifying macroalga to ocean acidification. *Proc Soc B: Biol Sci* 280 (1772): 20132201. DOI: 10.1098/rspb.2013.2201.
- Costa Jr OS, Attrill MJ, Pedrini AG, De-Paula JC. 2001. Benthic macroalgal distribution in coastal and offshore reefs at Porto Seguro Bay, Brazilian Discovery Coast. *Intl Soc Reef Stud Indonesia* 23-27.
- de Carvalho VF, de Fátima Oliveira-Carvalho M, Bandeira-Pedrosa ME, Pereira SMB. 2013. Benthic chlorophytes from a coastal island in the Oriental Northeast of Brazil. *Braz J Bot* 36: 203-210. DOI: 10.1007/s40415-013-0028-z.
- de Maria César Ferreira S, Lolis LA, Noga PMB, de Jesus Affe HM, de Castro Nunes JM. 2022. A highly diverse phytobenthic community along a short coastal reef gradient in northeastern Brazil. *Universitas Scientiarum* 27 (1): 34-56. DOI: 10.11144/JAVERIANA.SC271.AHDP.
- Díaz-Tapia P, Ly M, Verbruggen H. 2020. Extensive cryptic diversity in the widely distributed *Polysiphonia scopulorum* (Rhodomelaceae, Rhodophyta): molecular species delimitation and morphometric analyses. *Mol Phylogenet Evol* 152: 106909. DOI: 10.1016/j.ympev.2020.106909.
- Ding L, Ma Y, Huang B, Chen S. 2013. Effects of seawater salinity and temperature on growth and pigment contents in *Hypnea cervicornis* J. Agardh (Gigartinales, Rhodophyta). *BioMed Res Intl* 2013: 594308. DOI: 10.1155/2013/594308.
- Duarte CM, Gattuso JP, Hancke K, et al. 2022. Global estimates of the extent and production of macroalgal forests. *Global Ecol Biogeogr* 31 (7): 1422-1439. DOI: 10.1111/geb.13515.
- Eggert A. 2012. Seaweed Responses to Temperature. In: *Seaweed Biology. Ecological Studies*. Springer, Berlin, Heidelberg. DOI: 10.1007/978-3-642-28451-9_3.
- EL Boukhari MEM, Barakate M, Bouhija Y, Lyamlouli K. 2020. Trends in Seaweed Extract Based Biostimulants: Manufacturing Process and Beneficial Effect on Soil-Plant. *Plants* 9 (23): 1-23. DOI: 10.3390/plants9030359.
- Erlania, Radiarta IN. 2015. The use of seaweeds aquaculture for carbon sequestration: A strategy for climate change mitigation. *J Geodesy Geomatics Eng* 2: 109-115. DOI: 10.17265/2332-8223/2015.06.006.
- Erniati, Erlangga, Andika Y, Muliani. 2023. Seaweed diversity and community structure on the west coast of Aceh, Indonesia. *Biodiversitas* 24 (4): 2189-2200. DOI: 10.13057/biodiv/d240431.
- Estrada J, 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 (5): 1823-183. DOI: 10.13057/biodiv/d210508.
- Fabricsius KE, Crossman K, Jonker M, Mongin M, Thompson A. 2023. Macroalgal cover on coral reefs: Spatial and environmental predictors, and decadal trends in the Great Barrier Reef. *PLoS ONE* 18 (1): e0279699. DOI: 10.1371/journal.pone.0279699.
- Fauzie NA, Chang LS, Mustapha WA, Nor AR, Lim SJ. 2021. Functional polysaccharides of fucoidan, laminaran and alginate from Malaysian brown seaweeds (*Sargassum polycystum*, *Turbinaria ornata* and *Padina boryana*). *Intl J Biol Macromol* 167: 1135-1145. DOI: 10.1016/j.ijbiomac.2020.11.067.
- Fitrihastuti AN, Auliadani NM, Mudrikah S, Wulandari TM, Sayidinar A, Khairunnisa AD, Angellya BF, Utami LW. 2023. Macroalgal Abundance in the Intertidal Zone of Nglolang Beach, Gunungkidul, Yogyakarta. *Berkala Ilmiah Biologi* 14 (2): 16-24. DOI: 10.22146/bib.v14i2.5175.
- Florez JZ, Camus C, Hengst MB, Buschmann AH. 2017. A functional perspective analysis of macroalgae and epiphytic bacterial community interaction. *Front Microbiol* 8: 1-16. DOI: 10.3389/fmicb.2017.02561.
- Flores AAV, Christofoletti RA, Peres ALF, Ciotti AM, Navarrete SA. 2015. Interactive effects of grazing and environmental stress on macroalgal biomass in subtropical rocky shores: Modulation of bottom-up inputs by wave action. *J Exp Mar Biol Ecol* 463: 39-48. DOI: 10.1016/j.jembe.2014.11.001.
- Fong J, Lim ZW, Bauman AG, Valiyaveetil S, Liao LM, Yip ZT, Todd PA. 2019. Allelopathic effects of macroalgae on *Pocillopora acuta* coral larvae. *Mar Environ Res* 151: 1-8. DOI: 10.1016/j.marenvres.2019.06.007.
- Fulton CJ, Abesamis RA, Berkström C, Depczynski M, Graham NAJ, Holmes TH, Kulbicki M, Noble MM, Radford BT, Tano S, Tinkler P, Wernberg T, Wilson SK. 2019. Form and function of tropical macroalgal reefs in the Anthropocene. *Funct Ecol* 33 (6): 989-999. DOI: 10.1111/1365-2435.13282.
- Gakken. 1979. The seaweeds of Japan. Gakkan Illustrated Nature Encyclopedia, Tokyo.
- Gani P, Sunar NM, Matias-peralta HM, Apandi N. 2019. An overview of environmental factor's effect on the growth of microalgae. *J Appl Chem Nat Resour* 1 (2): 1-5.
- Graba-Landry AC, Löffler Z, McClure EC, Pratchett MS, Hoey AS. 2020. Impaired growth and survival of tropical macroalgae (*Sargassum* spp.) at elevated temperatures. *Coral Reefs* 39: 475-486. DOI: 10.1007/s00338-020-01909-7.
- Guo J, Qi M, Chen H, Zhou C, Ruan R, Yan X, Cheng P. 2022. Macroalgae-derived multifunctional bioactive substances: The potential applications for food and pharmaceuticals. In *Foods* 11 (21): 1-16. DOI: 10.3390/foods11213455.
- Guo Z, Wang L, Jiang Z, Liang Z. 2022. Comparison studies of epiphytic microbial communities on four macroalgae and their rocky substrates. *Mar Poll Bull* 176: 113435. DOI: 10.1016/j.marpolbul.2022.113435.
- Hadi S. 2004. Analisis regresi. Penerbit Andi Offset, Yogyakarta. [Indonesian]
- Handayani S, Widhiono I, Widyartini DS. 2023. Macroalgae diversity in the Pari Island Cluster, Seribu Islands District, Jakarta, Indonesia. *Biodiversitas* 24 (3): 1659-1667. DOI: 10.13057/biodiv/d240339.
- Harah MZ, Sidik BJ, Natrah FMI, Emmclan LSH, Hazma WN, Nordiah B. 2014. Seaweed community of Merambong shoal, Sungai Pulai estuary, Johor. *Malay Nat J* 66 (1): 117-131.
- Ji Y, Xu Z, Zou D, Gao K. 2016. Ecophysiological responses of marine macroalgae to climate change factors. *J Appl Phycol* 28 (5): 2953-2967. DOI: 10.1007/s10811-016-0840-5.
- Karsten U. 2012. Seaweed acclimation to salinity and desiccation stress. In *Seaweed biology: ecological studies (analysis and synthesis)* (pp. 87-107). Springer, Berlin Heidelberg. DOI: 10.1007/978-3-642-28451-9_5.
- Kase AGO, Rupidara ADN, Klila SR, Sabuna AC, Anakotta ARF, Meryanto Y, Emola IJ, Bessie, DM. 2019. Morphometric analysis, density and diversity of macroalga in Dara Mara marine waters, Anarae Village, Nuse Rote Ndao. *Ecol Environ Conserv* 25: S95-S99.
- Kepel RC, Lumingas LJL, Watung PMM, Mantiri DMH. 2019. Community structure of seaweeds along the intertidal zone of

- Mantehage Island, North Sulawesi, Indonesia. *AACL Bioflux* 12 (1): 87-101.
- Kepel RC, Mantiri DM, Sahami FM. 2020. Phylogeny and molecular identification of green macroalgae, *Ulva prolifera* (OF Müller, 1778) in Totok Bay, Maluku Sea, and Blongko waters, Sulawesi Sea, North Sulawesi, Indonesia. *AACL Bioflux* 13 (4): 2196-2203.
- Kim S, Choi SK, Van S, Kim ST, Kang YH, Park SR. 2022. Geographic differentiation of morphological characteristics in the brown seaweed *Sargassum thunbergii* along the Korean Coast: A response to local environmental conditions. *J Mar Sci Eng* 10 (4): 549. DOI: 10.3390/jmse10040549.
- Kokabi M, Yousefzadi M, Razaghi M, Feghhi MA. 2016. Zonation patterns, composition and diversity of macroalgal communities in the eastern coasts of Qeshm Island, Persian Gulf, Iran. *Mar Biodivers Rec* 9 (1): 1-11. DOI: 10.1186/s41200-016-0096-4.
- Kongkittayapun N, Chirapart A. 2011. Morphometric and molecular analysis of *Gracilaria salicornia* and its adelphoparasite in Thailand. *Sci Asia* 37: 6-16. DOI: 10.2306/scienceasia1513-1874.2011.37.006.
- Kumar MD, Kavitha S, Tyagi VK, Rajkumar M, Bhatia SK, Kumar G, Banu JR. 2022. Macroalgae-derived biohydrogen production: biorefinery and circular bioeconomy. *Biomass Conversion Biorefinery* 12 (3): 769-791. DOI: 10.1007/s13399-020-01187-x.
- Kustantinah, Hidayah N, Noviani CT, Astuti A, Paradhista DHV. 2022. Nutrients content of four tropical seaweed species from Kelapa Beach, Tuban, Indonesia and their potential as ruminant feed. *Biodiversitas* 23 (12): 6191-6197. DOI: 10.13057/biodiv/d231213.
- Lalegerie F, Gager L, Stiger-Pouvreau V, Connan S. 2020. The stressful life of red and brown seaweeds on the temperate intertidal zone: Effect of abiotic and biotic parameters on the physiology of macroalgae and content variability of particular metabolites. *Adv Bot Res* 95: 247-287. DOI: 10.1016/bs.abr.2019.11.007.
- Lamote M, Johnson LE, Lemoine Y. 2012. Photosynthetic responses of an intertidal alga to emersion: The interplay of intertidal height and meteorological conditions. *J Exp Mar Biol Ecol* 428: 16-23. DOI: 10.1016/j.jembe.2012.05.021.
- Lee WK, Lim YY, Leow ATC, Namasivayam P, Abdullah JO, Ho CL. 2017. Biosynthesis of agar in red seaweeds: A review. *Carbohydr Polym* 164: 23-30. DOI: 10.1016/j.carbpol.2017.01.078.
- Lee WK, Lim YY, Ho CL. 2019. pH affects growth, physiology and agar properties of agarophyte *Gracilaria changii* (Rhodophyta) under low light intensity from Morib, Malaysia. *Reg Stud Mar Sci* 30: 100738. DOI: 10.1016/j.rsma.2019.100738.
- Lemesle S, Rusig AM, Mussio I. 2023. Local scale high frequency monitoring of seaweed strandings along an intertidal shore of the English Channel (Luc-sur-Mer, Normandy France)-Effect of biotic and abiotic factors. *Aquatic Botany* 186: 103616. DOI: 10.1016/j.aquabot.2023.103616.
- Lenzo D, Colangelo MA, Pasteris A, Rindi F, Pistocchi R, Pezzolesi L. 2023. Understanding the role of macroalgal complexity and allelochemicals production in invasive and non-invasive macroalgae in the North-Western Adriatic Sea: Effect on the associated communities. *Water (Switzerland)* 15 (9): 1-26. DOI: 10.3390/w15091697.
- Li J, Liu Y, Liu Y, Wang Q, Gao X, Gong Q. (2019). Effects of temperature and salinity on the growth and biochemical composition of the brown alga *Sargassum fusiforme* (Fucales, Phaeophyceae). *J Appl Phycol* 31: 3061-3068. DOI: 10.1007/s10811-019-01795-9.
- Limmon G.V, Haulussy Z, Loupaty SR, Manuputty GD. 2023. Corals diversity at waters of Southern Ambon Island, Maluku. *AIP Conf Proc* 2588 (01): 030008. DOI: 10.1063/5.0111963.
- Lin SM, Tseng LC, Ang PO, Bolton J, Liu LC. 2018. Long-term study on seasonal changes in floristic composition and structure of marine macroalgal communities along the coast of Northern Taiwan, southern East China Sea. *Mar Biol* 165 (5): 1-17. DOI: 10.1007/s00227-018-3344-9.
- Litaay C. 2014. Sebaran dan keragaman komunitas makro algae di perairan Teluk Ambon. *Jurnal Ilmu dan Teknologi Kelautan Tropis* 6 (1): 131-142. DOI: 10.28930/jitkt.v6i1.8636. [Indonesian]
- Litaay C, Arfah H, Rugebregt MJ, Opier RDA. 2021. Species diversity, density, phosphate concentration and the utilization of algae as a food material. *IOP Conf Ser: Earth Environ Sc* 777 (1): 012004. DOI: 10.1088/1755-1315/777/1/012004.
- Lumuindong F, Yapanto LM. 2023. Configuration of the phytoplankton community in the Banda Sea, Central Maluku. *Adv Water Sci* 32 (2): 1-10.
- Manikandan DB, Veeran S, Seenivasan S, Sridhar A, Arumugam M, Yangen Z, Ramasamy T. 2022. Exploration of marine red seaweed as a dietary fish meal replacement and its potentiality on growth, hematological, biochemical, and enzyme activity in freshwater fish *Labeo rohita*. *Trop Anim Health Prod* 54 (6): 395. DOI: 10.1007/s11250-022-03392-4.
- Meinita MDN, Akromah N, Andriyani N, Setijanto S, Harwanto D, Liu T. 2021. Molecular identification of *Gracilaria* species (Gracilariales, Rhodophyta) obtained from the South Coast of Java Island, Indonesia. *Biodiversitas* 22 (7): 3046-3056. DOI: 10.13057/biodiv/d220759.
- Melsasail K, Awan A, Papiyaya PM, Rumahlatu D. 2018. The ecological structure of macroalgae community (Seagrass) on various zones in the coastal waters of Nusalaut Island, Central Maluku District, Indonesia. *AACL Bioflux* 11 (4): 957-966.
- Mena F, Wijesinghe PAU, Thiripuranathar G, Uzair B, Iqbal H, Khan BA, Mena B. 2020. Ecological and industrial implications of dynamic seaweed-associated microbiota interactions. *Mar Drugs* 18 (12): 641. DOI: 10.3390/md18120641.
- Meynard A, Zapata J, Salas N, Betancourt C, Pérez-Lara G, Castañeda F, Ramírez M, Contador C, Guillemín M, Porcia L. 2019. Genetic and morphological differentiation of *Porphyra* and *Pyropia* species (Bangiales, Rhodophyta) coexisting in a rocky intertidal in Central Chile. *J Phycol* 55 (2): 297-313. DOI: 10.1111/jpy.12829.
- Monteil Y, Teo A, Fong J, Bauman AG, Todd PA. 2020. Effects of macroalgae on coral fecundity in a degraded coral reef system. *Mar Poll Bull* 151: 110890. DOI: 10.1016/j.marpolbul.2020.110890.
- Monteiro C, Li H, Diehl N, Collén J, Heinrich S, Bischof K, Bartsch I. 2021. Modulation of physiological performance by temperature and salinity in the sugar kelp *Saccharina latissima*. *Phycol Res* 69 (1): 48-57. DOI: 10.1111/pre.12443.
- Moreira A, Cruz S, Marques R, Cartaxana P. 2022. The underexplored potential of green macroalgae in aquaculture. *Rev Aquac* 14 (1): 5-26. DOI: 10.1111/raq.12580.
- Mushlihah H, Amri K, Faizal A. 2021. Diversity and distribution of macroalgae to environmental conditions of Makassar City. *Jurnal Ilmu Kelautan* 7 (1): 16-26.
- Harah MZ, Sidik J, Hazma W, Nordiah B. 2014. Seaweed community of the Merambong shoal, Sungai Pulai estuary, Johore. *Malay Nat J* 66 (2): 132-148.
- Navarro-Barranco C, Muñoz-Gómez B, Saiz D, Ros M, Guerra-García JM, Altamirano M, Ostalé-Valriberas E, Moreira J. 2019. Can invasive habitat-forming species play the same role as native ones? The case of the exotic marine macroalga *Rugulopteryx okamurae* in the Strait of Gibraltar. *Biol Invasions* 21 (11): 3319-3334. DOI: 10.1007/s10530-019-02049-y.
- Neustupa J, Nemcova Y. 2020. Morphometric analysis of surface utricles in *Halimeda tuna* (Bryopsidales, Ulvophyceae) reveals variation in their size and symmetry within individual segments. *Symmetry* 12 (8): 1271. DOI: 10.3390/sym12081271.
- Neustupa J, Nemcova Y. 2018. Morphological allometry constrains symmetric shape variation, but not asymmetry, of *Halimeda tuna* (Bryopsidales, Ulvophyceae) segments. *PLoS ONE* 13 (10): e0206492. DOI: 10.1371/journal.pone.0206492.
- Pattikawa JA. 2018. Community structure of reef fish in the southern waters of Ambon Island, eastern Indonesia. *AACL Bioflux* 11 (3): 919-924.
- Pei P, Aslam M, Du H, Liang H, Wang H, Liu X, Chen W. 2021. Environmental factors shape the epiphytic bacterial communities of *Gracilariopsis lemaneiformis*. *Sci Rep* 11 (1): 1-15. DOI: 10.1038/s41598-021-87977-3.
- Pereira DT, Simioni C, Filipin EP, Bouvie F, Ramlov F, Maraschin M, Bouzon ZL, Schmidt ÉC. 2017. Effects of salinity on the physiology of the red macroalga, *Acanthophora spicifera* (Rhodophyta, Ceramiales). *Acta Bot Brasilia* 31 (4): 555-565. DOI: 10.1590/0102-33062017abb0059.
- Pereira SG, Pereira RN, Rocha CM, Teixeira JA. 2023. Electric fields as a promising technology for the recovery of valuable bio compounds from algae: Novel and sustainable approaches. *Bioresour Technol Rep* 22: 101420. DOI: 10.1016/j.biteb.2023.101420.
- Pezzolesi L, Accoroni S, Rindi F, Samorì C, Totti C, Pistocchi R. 2021. Survey of the allelopathic potential of Mediterranean macroalgae: production of long-chain polyunsaturated aldehydes (PUAs). *Phytochemistry* 189: 112826. DOI: 10.1016/j.phytochem.2021.112826.

- Pise NM, Gaikwad DK, Jagtap TG. 2013. Oxidative stress and antioxidant indices of the marine red alga *Porphyra vietnamensis*. *Acta Bot Croat* 72 (2): 197-209. DOI: 10.2478/v10184-012-0024-6.
- Rahardjanto A, Husamah, Hadi S, Rofieq A, Wahyono P. 2020. Community structure, diversity, and distribution patterns of sea cucumber (Holothuroidea) in the coral reef area of Sapeken Islands, Sumenep Regency, Indonesia. *AACL Bioflux* 13 (4): 1795-1811.
- Raza'l TS, Amrifo V, Putra IP, Febrianto T, Ilhamdy AF. 2021. Natural productivity, morphometrics and seasonal distribution of *Caulerpa racemosa*. *E3S Web Conf* 324: 03010. DOI: 10.1051/e3sconf/202132403010.
- Roleda MY, Hurd CL. 2019. Seaweed nutrient physiology: Application of concepts to aquaculture and bioremediation. *Phycologia* 58 (5): 552-562. DOI: 10.1080/00318884.2019.1622920.
- Rouhani E, Safari R, Imanpour M, Hoseinifar S, Yazici M, El-Haroun E. 2022. Effect of dietary administration of green macroalgae (*Ulva intestinalis*) on mucosal and systemic immune parameters, antioxidant defence, and related gene expression in zebrafish (*Danio rerio*). *Aquacult Nutr* 2022: 1-11. DOI: 10.1155/2022/7693468.
- Rugebregt MJ, Arfah H, Pattipeilohy F. 2020. Correlation between macroalgae diversity and water quality in Southwest Maluku waters. *Mar Res Indones* 45 (1): 25-32. DOI: 10.14203/mri.v45i1.573.
- Salgado A, Moreira-Leite B, Afonso A, Infante P, Mata P. 2023. Chocolates enriched with seaweed: Sensory profiling and consumer segmentation. *Intl J Gastronomy Food Sci* 33: 100747. DOI: 10.1016/j.ijgfs.2023.100747.
- Sampaio E, Rodil IF, Vaz-Pinto F, Fernández A, Arenas F. 2017. Interaction strength between different grazers and macroalgae mediated by ocean acidification over warming gradients. *Mar Environ Res* 125: 25-33. DOI: 10.1016/j.marenvres.2017.01.001.
- Sangil C, Martins GM, Hernández JC, Alves F, Neto AI, Ribeiro C, Leon-Cisneros K, Canning-Clode Joao, Rosas-Alquicira E, Mendoza JC, Titley I, Couto RP, Kaufmann M. 2018. Shallow subtidal macroalgae in the North-eastern Atlantic archipelagos (Macaronesian region): a spatial approach to community structure. *Eur J Phycol* 53(1): 83-98. DOI: 10.1080/09670262.2017.1385098.
- Sangil C, Afonso-Carrillo J, Sansón M. 2021. Effect of substrate size and depth on macroalgal communities in unstable marine rocky bottoms. *Aquat Bot* 173: 103411. DOI: 10.1016/j.aquabot.2021.103411.
- Santiañez WJE, Trono JrGC. 2013. Taxonomy of the Genus *Sargassum* (Fucales, Phaeophyceae) from Alabat Island, Quezon, Northeastern Philippines. *Sci Diliman* 25 (1): 29-50.
- Sari DK, Rahardjanto A, Purwanti E, Permana TI, Fauzi A. (2019). The Formulation of Artificial Nori with the Base Mixture Ingredients of *Gracilaria* sp. and *Arenga pinnata* (Wurmb) Merr. using the Natural Colorant from *Pleomele angustifolia* (Medik.) NE Br. *IOP Conf Ser: Earth Environ Sci* 276 (1): 012013. DOI: 10.1088/1755-1315/276/1/012013.
- Serisawa Y, Akino H, Matsuyama K, Ohno M, Tanaka J, Yokohama Y. 2002. Morphometric study of *Ecklonia cava* (Laminariales, Phaeophyta) sporophytes in two localities with different temperature conditions. *Phycol Res* 50 (3): 193-199. DOI: 10.1046/j.1440-1835.2002.00273.x.
- Sissini MN, Koerich G, de Barros-Barreto MB, Coutinho LM, Gomes FP, Oliveira W, Costa IO, Nunes JMDC, Henriques MC, Vieira-Pinto T, Torrano-Silva BN, Oliveira MC, Le Gall L, Horta PA. 2022. Diversity, distribution, and environmental drivers of coralline red algae: the major reef builders in the Southwestern Atlantic. *Coral Reefs* 41 (3): 711-725. DOI: 10.1007/s00338-021-02171-1.
- Sheikhzadeh N, Ahmadifar E, Soltan, M, Tayefi-Nasrabadi H, Mousavi S, Naiel MA. 2022. Brown Seaweed (*Padina australis*) extract can promote performance, innate immune responses, digestive enzyme activities, intestinal gene expression and resistance against *Aeromonas hydrophila* in Common Carp (*Cyprinus carpio*). *Animals* 12 (23): 3389. DOI: 10.3390/ani12233389.
- Sofiana MSJ, Nurrahman YA, Warsidah, Minsas S, Yuliono A, Safitri I, Helena S, Risiko. 2022. Community structure of macroalgae in Lemukutan Island. *Jurnal Ilmu Kelautan* 8 (1): 1-8.
- Sompong U, Mingkaew J, Amornlerdpison D, Mengumphan K. 2020. Sea grape (*Caulerpa lentillifera*) cultivation in artificial seawater closed system. *Maejo Intl J Energy Environ Commun* 2 (1): 17-22. DOI: 10.54279/mjjeec.v2i1.244947.
- Srimariana ES, Kawaroe M, Lestari DF, Setyaningsih WA, Nugraha AH. 2020. Biodiversity of macroalgae in Pari Island. *IOP Conf Ser: Earth Environ Sci* 429 (1): 0-5. DOI: 10.1088/1755-1315/429/1/012018.
- Steigleder KM, Copertino MS, Lanari M, Camargo MFM. 2019. Latitudinal gradient in intertidal seaweed composition off the coast of southern Brazil and Uruguay. *Aquat Bot* 156: 47-56. DOI: 10.1016/j.aquabot.2019.04.003.
- Sumandiarsa IK, Bengen DG, Santoso J, Januar HI. 2021. The relationship between seasonal and environmental variations with morphometric characteristics of *Sargassum polycystum* (C. Agardh. 1824) from Tidung, Sebesi and Bintan Islands waters, Indonesia. *Polish J Nat Sci* 36 (1): 37-57. DOI: 10.31648/pjns.7305.
- Sura SA, Bell A, Kunes KL, Turba R, Songer R, Fong P. 2021. Responses of two common coral reef macroalgae to nutrient addition, sediment addition, and mechanical damage. *J Exp Mar Biol Ecol* 536: 1-8. DOI: 10.1016/j.jembe.2021.151512.
- Swan K, McPherson J, Seddon PJ, Moehrensclager A. 2016. Managing marine biodiversity: The rising diversity and prevalence of marine conservation translocations. *Conserv Lett* 9 (4): 239-251. DOI: 10.1111/conl.12217.
- Takolander A, Cabeza M, Leskinen E. 2017. Climate change can cause complex responses in Baltic Sea macroalgae: A systematic review. *J Sea Res* 123: 16-29. DOI: 10.1016/j.seares.2017.03.007.
- Titlyanov EA, Titlyanova TV, Tokeshi M, Li X. 2019. Inventory and historical changes in the marine flora of Tomioka Peninsula (Amakusa Island), Japan. *Diversity* 11 (9): 158. DOI: 10.3390/d11090158.
- Tiwari BK, Troy DJ. 2015. Chapter 1—Seaweed sustainability - food and nonfood applications. In: Tiwari BK, Troy DJ. (eds.). *Seaweed Sustainability*. Academic Press 1-6. DOI: 10.1016/B978-0-12-418697-2.00001-5.
- Umanzor S, Li Y, Bailey D, Augyte S, Huang M, Marty-Rivera M, Yarish C, Lindell S. 2021. Comparative analysis of morphometric traits of farmed sugar kelp and skinny kelp, *Saccharina* spp., strains from the Northwest Atlantic. *J World Aquacult Soc* 52 (5): 1059-1068. DOI: 10.1111/jwas.12783.
- Veeragurunathan V, Mandal SK, Vizhi JM, Grace PG, Gurumoorthy U. 2022. Studies on seaweeds diversity along the intertidal zone of islands of Gulf of Mannar Marine Biosphere Reserve, India for policy and management recommendation. *J Coastal Conserv* 26 (4): 28. DOI: 10.1007/s11852-022-00878-z.
- Verbruggen H, De Clerck O, Coppejans E. 2005. Deviant segments hamper a morphometric approach towards Halimeda taxonomy. *Cryptogam Algal* 26 (3): 259-274.
- Vieira C, De Ramon N'Yeurt A, Rasoamanendrika FA, D'Hondt S, Tran LAT, Van den Spiegel D, Kawai H, De Clerck O. 2021. Marine macroalgal biodiversity of northern Madagascar: morpho-genetic systematics and implications of anthropic impacts for conservation. *Biodivers Conserv* 30 (5): 1-12. DOI: 10.1007/s10531-021-02156-0.
- Wahl M, Barboza FR, Buchholz B, Dobretsov S, Guy-Haim T, Rilov G, Schuett R, Wolf F, Vajedsamiei J, Yazdanpanah M, Pansch C. 2021. Pulsed pressure: Fluctuating impacts of multifactorial environmental change on a temperate macroalgal community. *Limnol Oceanogr* 66 (12): 4210-4226. DOI: 10.1002/lno.11954.
- Wernberg T, de Bettignies T, Joy BA, Finnegan PM. 2016. Physiological responses of habitat-forming seaweeds to increasing temperatures. *Limnol Oceanogr* 61 (6): 2180-2190. DOI: 10.1002/lno.10362.
- Widyartini DS, Hernayanti, Prabowo RE. 2021. Composition and diversity of macroalgae community in the coast of Karang Bolong, Nusakambangan Island. *IOP Conf Ser Earth Environ Sci* 746 (1): e012025. DOI: 10.1088/1755-1315/746/1/012025.
- Widyartini DS, Insan AI, Hidayah HA. 2023. Diversity and distribution of phaeophyta macroalgae in Pedalen Coastal Waters, Kebumen. *Jurnal Ilmu Pertanian Indonesia* 28 (1): 65-71. DOI: 10.18343/jipi.28.1.65.
- Wirawan IGP, Dewi NKES, Sasadara MMV, Sunyamarthi IGNA, Jawi IM, Wijaya IN, Darmawati IAP, Suada IK, Krisnandika AAK. 2022. Phytochemical analysis and molecular identification of green macroalgae *Caulerpa* spp. from Bali, Indonesia. *Molecules* 27 (15): 4879. DOI: 10.3390/molecules27154879.
- Yap-Dejeto LG, Fabillo M, Sison-Mangus M. 2022. Biodiversity of *Sargassum* (Fucales, Sargassaceae) from Eastern Samar (Philippines) inferred from nuclear ribosomal internal transcribed spacer (ITS) sequence data. *Appl Phycol* 3 (1): 422-434. DOI: 10.1080/26388081.2022.2119164
- Yñiguez AT, McManus JW, Collado-Vides L. 2010. Capturing the dynamics in benthic structures: environmental effects on morphology in the macroalgal genera Halimeda and Dictyota. *Marine Ecology Progress Series* 411: 17-32. DOI: DOI: 10.3354/meps08643

- Zainee NFA, Ismail A, Taip ME, Ibrahim N, Ismail A. 2019. Habitat preference of seaweeds at a tropical island of southern Malaysia. *Songklanakarin J Science & Technology* 41(5): 1171-1177. DOI: 10.14456/sjst-psu.2019.147
- Zulpikar F, Handayani T. 2021. Life form, diversity, and spatial distribution of macroalgae in Komodo National Park waters, East Nusa Tenggara. *IOP Conference Series: Earth and Environmental Science* 944(1): 012026. DOI: 10.1088/1755-1315/944/1/012026