Seaweed communities in the coastal waters of Likupang Marine Station, Tongkaina and Kora-kora, North Sulawesi, Indonesia

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Abstract. This present study was conducted to determine the biodiversity and community structure of seaweeds in the coastal waters of Likupang Marine Station, Tongkaina and Kora-kora, North Sulawesi Indonesia. The line transect method was used to identify and quantify the seaweeds abounding the three established stations. Each station was divided into three transects, and each transect into ten quadrates. Species richness index, diversity index, evenness index and dominance index were calculated to determine diversity of seaweeds along the study area. 31 different species of seaweeds were identified in the study area, belonging to Rhodophyta (Rhodomelaceae, Lithophyllaceae, Galaxauraceae, Gracilariaceae, Cryptonemiaceae, Solieriaceae, Cystocloniaceae), Phaeophyta (Dictyotaceae, Sargassaceae) and Ulvophyceae (Caulerpaceae, Halimedaceae, Dichotomosiphonaceae, Chaemorphaceae, Valoniaceae, Dasycladaceae, Ulvaceae). The seaweed species identified also have different densities ranging from 0.03 to 3.57 per m^2. The most abundant seaweed species across the three stations were *Halimeda opuntia* and *Gracilaria edulis*. *G. edulis* had the highest density and *T. decurrens, A. fragilis, V. aegagropila, D. versluysii, C. sertularioides, H. tuna,* and *C. lentillifera* had the lowest densities. The dominance index was highest at station 2, and lowest at station 1. Station 1 had the highest species richness and station 2 the lowest species richness. Station 1 recorded the highest diversity and station 2 the lowest diversity. Evenness index was highest at station 1, while the lowest was at station 2. The three sampling stations were divided into 2 groups based on an abundance of 31 species of seaweeds. The two groups are Group I (Tongkaina), and Group II (Likupang Marine Station and Kora-kora). Apparently, the two station groups are related to the type of sediment and coverage of seagrass.
Key Words: diversity, dominance, evenness, macroalgae, richness.

Introduction. Algae are very simple, chlorophyll-containing organisms (Bold & Wynne 1985). Algae are a heterogeneous group of plants that have two major types: the macroalgae (seaweeds) occupy the littoral zone. They include green, brown, and red algae. Microalgae (phytoplankton) are found in both benthic and littoral habitats (Garson 1989). Macroalgae are classified into three higher taxa: brown (Class Phaeophyceae), red (phylum Rhodophyta) and green (phylum Chlorophyta), based on their pigmentation (FAO 2004). Macroalgae is a collective term referring to a series of non-phylogenetic (Suutari et al 2015), multicellular (Renita & Amarnath 2010), macroscopic (Klöser et al 1996) and eukaryotic organisms. Macroalgae are macroscopic benthic marine algae living in the intertidal zone. They are characterized by autotrophic nutrition and fast-growth. They do not need land for cultivation and their growth rate is faster than that of terrestrial plants (Wan et al 2019). The high genetic diversity of seaweeds is reflected in the high diversity of their morphological, ultrastructural, ecological, biochemical, and physiological traits (Rindi et al 2012).

Algae are distributed in diverse and extreme environments (Brodie & Lewis 2007). Macroalgae are growing attached to rocks and along the sea shore and they are found in a range of aquatic habitats (Raven & Giordano 2014). The distribution of seaweeds depends upon many factors such as physical (substrate, temperature, light quality and quantity, dynamic tidal activity, winds, and storms), chemical (salinity, pH, nutrients, gases, and pollution level), and biological factors (herbivores, microbes, epiphytes, endophytes, symbionts, parasites, and diseases) (Baweja et al 2016).

Macroalgae is widespread in tropical waters, including in Indonesia, which has a potential of 6.42% of the total world macroalgae biodiversity (Surono 2004). The results of the Siboga Expedition in 1899-1900 in Indonesian waters showed that there were 782 species of marine algae discovered, consisting of 196 species of green algae, 452 species of red algae, and 134 species of brown algae (Weber-van Bosse 1913, 1921, 1923, 1928). In North Sulawesi Province, there were 14 species in Blongko waters, South Minahasa (Kepel et al 2018a), 8 species in Bahoi, North Minahasa (Baino et al 2019), 45 species in Mantehage Island (Kepel et al 2019a), 35 species in the Minahasa Peninsula in the rainy season (Kepel et al 2019b) and 19 species in the dry season (Kepel et al 2020), 6 species in Tanjung Merah, Bitung (Achmad et al 2021), 15 species in Ondong, Siau Tagulandang Biaro (Kandati et al 2021), 7 species in Bombuyanoi Island (Patra et al 2021), 6 species in Molas, Manado (Hadath et al 2023) and 16 species in Tanjung Merah, Rap-rap and Totok Bay (Kepel et al 2023).

In polluted environmental conditions, *Ulva* sp. and *Halimeda opuntia* were found in the waters of Totok Bay and Blongko (Kepel et al 2018b; Mantiri et al 2018), *Padina australis* in the waters of Totok Bay, Manado Bay, Talawaan Bajo and Likupang (Mantiri et al 2019a), and some other macroalgae in the Minahasa Peninsula (Tombokan et al 2020).

This present study was conducted to determine the species composition, density and diversity of seaweeds in three research sites (Likupang Marine Station, Tongkaina, Kora-kora) found along the intertidal zone of North Sulawesi, Indonesia.

Material and Method

Study area. This research was conducted from April to June 2023. The research sites were in the coastal waters of Likupang Marine Station, East Likupang Sub-District, North Minahasa Regency (Station 1), in the coastal waters of Tongkaina, Bunaken Sub-District, Manado City (Station 2), and in the coastal waters of Kora-kora, Lembean Timur Sub-District, Minahasa Regency (Station 3), North Sulawesi Province, Indonesia (Figure 1). Data collection of seaweeds was carried out in 3 points, namely Station 1, Station 2, and Station 3. In Station 1, there was a rocky substrate with less dense seagrass near the coast. Station 2 had mostly a muddy sand substrate with dense seagrass near the coast. Station 3 mostly had a sand substrate largely covered with seagrass near the coast, with some shallow ponds.

Sampling techniques. This research was carried out using the line transect method with quadratic sampling technique (Krebs 1999). The transects in each location consisted of 3 lines of 100 m length, perpendicular to the coastline with the assumption that the distribution of the community is even. The distance between transects was 5 m and the distance between squares was 10 m. The determinations were done at the lowest ebb with the square size of 1x1 m^2.

The first square was placed near the land, where the first seaweeds were found and the last square in the last part of the seaweeds. Likewise, the other nine points were determined systematically between the first box and the last box. The length of the transect was divided by the number of boxes. Inventory was carried out by roaming survey method at the specified research location. Determination of the individual seaweed contained in the squares was done by calculating the number of stands.

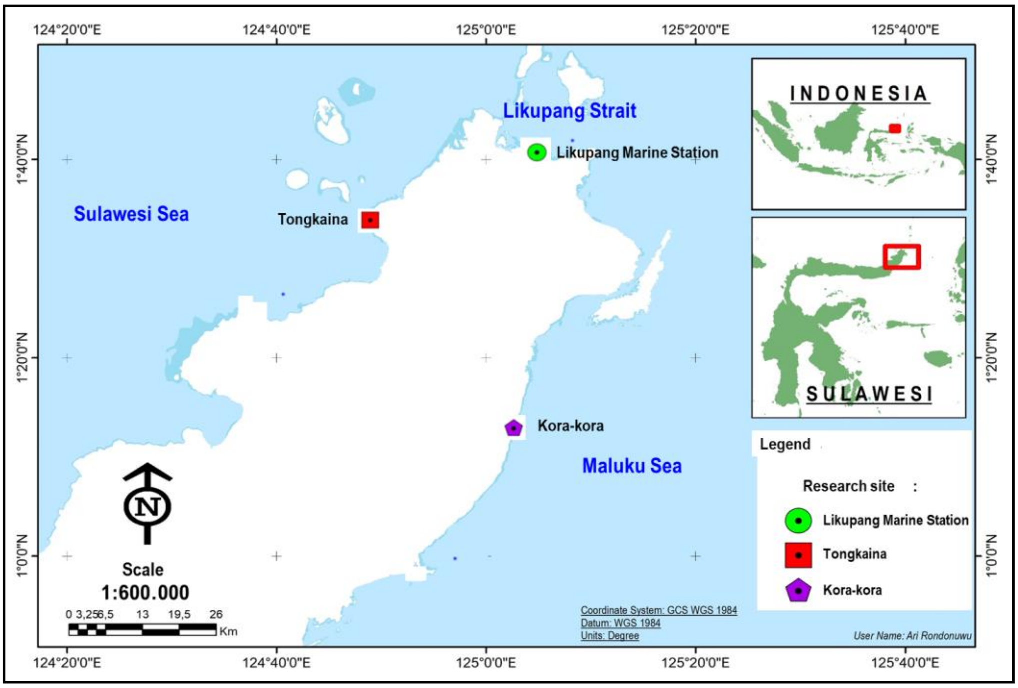

Figure 1. Map of research stations.

Sample identification. Identification of samples was carried out based on Trono & Ganzon-Fortes (1988), Calumpong & Meñez (1997), and Trono (1997).

Species density. Species density was calculated using the following formula (Krebs 1999):

Species density = Number of individuals per species / The area of sampling

Richness index. The Richness index (R) was calculated using the formula (Ludwig & Reynolds 1988):

$$R=(S-1)/\ln(N)$$

Where: S - number of species; N - total number of individuals.

Diversity index. Shannon's diversity index (H') was calculated using the formula (Ludwig & Reynolds 1988):

$$H' = -\sum\left(\frac{ni}{N}\right)\ln\sum\left(\frac{ni}{N}\right)$$

Where: ni is the number of individuals of i-th species and N is total number for all S species in the population.

Evenness index. The Evenness index (E) is calculated using the formula (Ludwig & Reynolds 1988):

$$E = \frac{H'}{H'\,max}$$

Where: E - evenness index; H'max - maximum value of the diversity index.

Dominance index. The Dominance index was calculated using the following formula (Odum 1971):

$$D = \sum \left(\frac{ni}{N}\right)^2 = \sum Pi^2$$

Where: ni - the number of individuals of i-th species and N is total number for all species, Pi is $(ni/N)^2$.

Correspondence analysis. Correspondence analysis (CA) provides a geometric presentation in which the studied variable is mapped into points in the cross axis. CA is suitable for analyzing variables and observations that have been presented in the form of contingency tables or matrices (Lebart et al 1982). The CA application in this study aims to provide the best presentation simultaneously between species groups (i rows) and station groups (j columns), to obtain the correct correspondence or relationship between the two variables studied (species and stations). The notations used are:

$k=\sum\sum k_{ij}$ - effective total individuals (total amount)

$f_{ij}=k_{ij}/k$ - relative frequency

$f_{i.}=\sum f_{ij}$ - relative marginal frequency

$f_{j.}=\sum f_{ij}$ - relative marginal frequency

In this case, the distance between 2 species i and i' is given by the formula (distance $\chi 2$):

$$d^2(i, i') = \sum_{j=1}^{p} \frac{1}{f_{.j}} \left(f_{ij}/f_{i.} - f_{i'j}/f_{i'.}\right)^2$$

In the same way, the distance between 2 stations j and j' is obtained with the formula:

$$d^2(j, j') = \sum_{i=1}^{n} \frac{1}{f_{i.}} \left(f_{ij}/f_{.j} - f_{ij'}/f_{.j'}\right)^2$$

According to Lebart et al (1982), this weighted distance has the advantage of meeting the principle of "equivalence distribution". Another advantage of using distance $\chi 2$ in CA is that variable and observation roles are symmetrical and are not affected by the presence of double absences on distance stability.

Two series of coefficients for each element of the two corresponding groups were calculated to interpret certain axes in the CA. This data display in the two-way contingency table through CA is done using the STATGRAPHICS Centurion packaging program through the CA menu selection.

Results and Discussion

Species composition. There were 31 species of seaweeds identified from 16 families belonging to Rhodophyceae, Phaeophyceae, and Ulvophyceae (Table 1). Station 1 had 21 species, Station 2 had 18 species and Station 3 had 20 species.

Table 1

Summary of identified seaweeds species

No	*Class*	*Order*	*Family*	*Species*
1	Rhodophyceae	Ceramiales	Rhodomelaceae	*Laurencia papillosa*
2		Corallinales	Lithophyllaceae	*Amphiroa fragilissima*
3		Nemaliales	Galaxauraceae	*Galaxaura oblongata*
4				*Actinotrichia fragilis*
5		Gracilariales	Gracilariaceae	*Glacilaria edulis*
6		Cryptonemiales	Cryptonemiaceae	*Halymenia duvillaei*
7		Gigartinales	Solieriaceae	*Eucheuma* sp.
8			Cystocloniaceae	*Hypnea boergesenii*
9				*Hypnea musciformis*
10	Phaeophyceae	Dictyotales	Dictyotaceae	*Dictyota dichotoma*
11				*Padina australis*
12		Fucales	Sargassaceae	*Turbinaria decurrens*
13				*Turbinaria ornata*
14	Ulvophyceae	Bryopsidales	Caulerpaceae	*Caulerpa racemosa*
15				*Caulerpa lentillifera*
16				*Caulerpa sertularioides*
17			Halimedaceae	*Halimeda macroloba*
18				*Halimeda opuntia*
19				*Halimeda cylindracea*
20				*Halimeda discoidea*
21				*Halimeda simulans*
22				*Halimeda tuna*
23			Dichotomosiphonaceae	*Avrainvillea erecta*
24		Cladophorales	Chaetomorphaceae	*Chaetomorpha crassa*
25				*Boodlea composita*
26			Valoniaceae	*Valonia aegagropila*
27				*Valonia fastigiata*
28				*Dictyosphaeria versluysii*
29		Dasycladales	Dasycladaceae	*Neomeris annulata*
30				*Bornetella sphaerica*
31		Ulvales	Ulvaceae	*Ulva reticulata*

The results of Kepel et al (2019a) showed that the number of seaweed species along the intertidal zone of Mantehage Island was 45, 35 species in the wet season on the Minahasa Peninsula (Kepel et al 2019b), and 23 species in the dry season on the Minahasa Peninsula (Kepel et al 2020). The number of species in the current study is lower than the results of the study in the coastal waters of Mantehage Island and in the rainy season on the Minahasa Peninsula, but higher than in the dry season on the Minahasa Peninsula. The number of seaweed species can vary based on seasonal differences, but also on other environmental factors.

Density parameter and number of species. The density of seaweeds found in Station 1 is presented in Figure 2. In Station 1, there were 21 species having a density between 0.03-2.20 ind m^{-2}, with an average density of 0.42 ind m^{-2}, with *H. opuntia* having the highest density (2.2 ind m^{-2}), and *T. decurrens* and *A*. *fragilis* the lowest (0.03 ind m^{-2}).

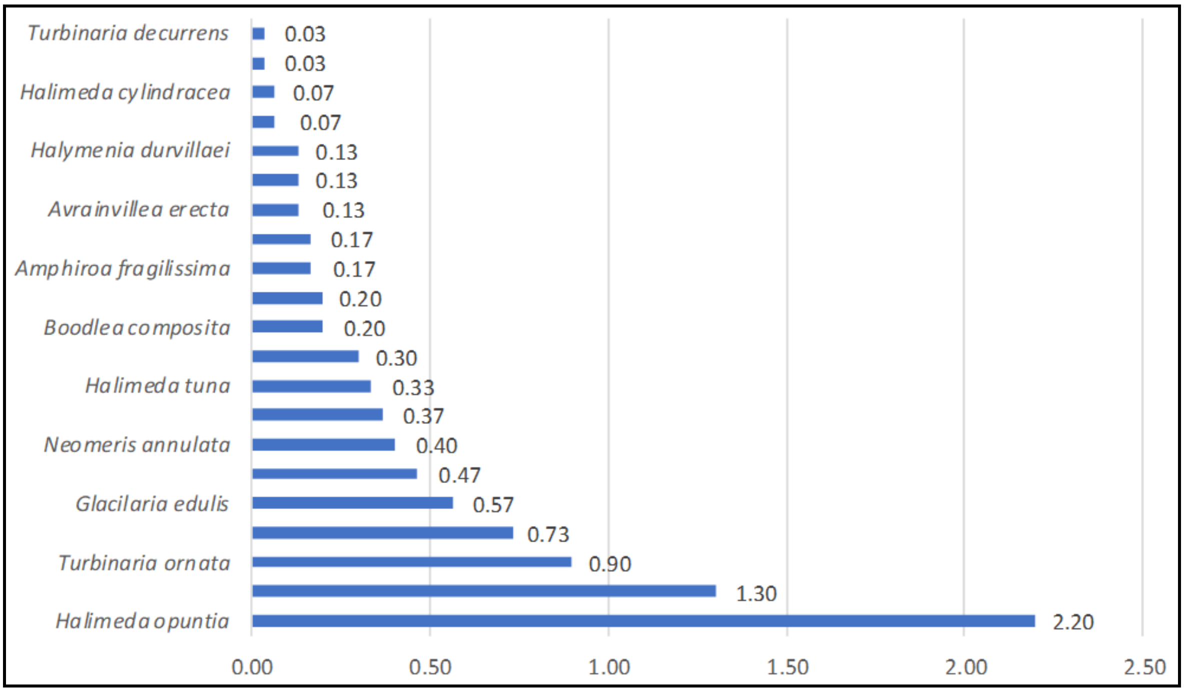

Figure 2. Density (ind m^{-2}) of seaweeds in Station 1 (Likupang Marine Station).

In Station 2, there were 18 species having a density between 0.03-3.57 ind m^{-2} with an average density of 0.6 ind m^{-2}, with *G. edulis* having the highest density of 3.57 ind m^{-2}. *V. aegagropila, D. versluysii* and *C. sertularioides* had the lowest density of 0.03 ind m^{-2} (Figure 3).

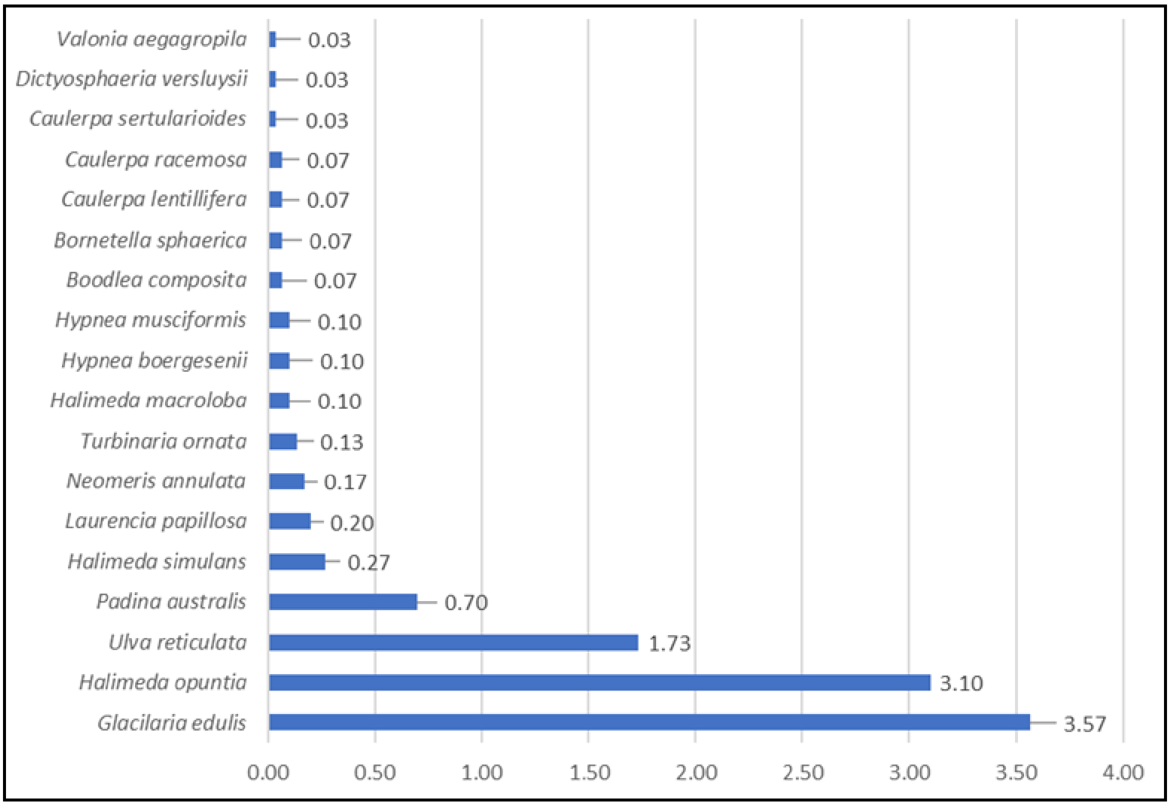

Figure 3. Density (ind m^{-2}) of seaweeds in Station 2 (Tongkaina).

There were 20 species in Station 3 with a density between 0.03-1.10 ind m^{-2}, with an average density of 0.34 ind m^{-2}. *H. opuntia* had the highest density, of 1.17 ind m^{-2}, and the lowest density was obtained for *H. tuna, C. letillifera* and *A. fragilis*, of 0.03 ind m^{-2} (Figure 4).

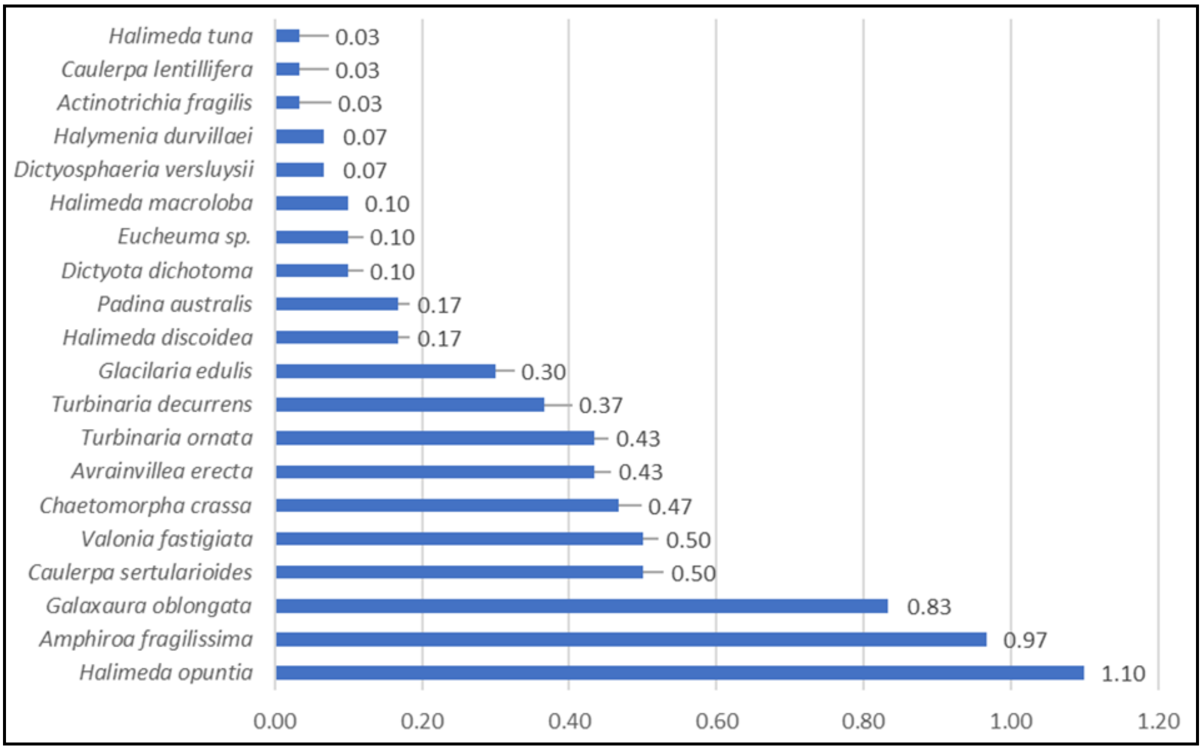

Figure 4. Density (ind m^{-2}) of seaweeds in Station 3 (Kora-kora).

Dominance, Diversity, Evenness, Richness indices. Based on the calculation of several ecological indices from seaweeds at each station, the values of D, H´, E, and R, are present in Table 2.

Table 2

Value of seaweeds community indices

Station	*D*	*H´*	*E*	*R*
1	0.2524	2.2762	0.7476	3.5796
2	0.3743	1.8085	0.6257	2.9536
3	0.3502	1.9466	0.6498	3.5760

The dominance index value was highest at Station 2 (0.3743), followed by Station 3 (0.3502), and Station 1 (0.2524). The diversity index value was highest in Station 1 (2.2726), followed by Station 3 (1.9466), and Station 2 (1.8085). The evenness index value was highest at Station 1 (0.7476), followed by Station 3 (0.6498), and Station 2 (0.6257). The richness index value was highest at Station 1 (3.5796), followed by Station 3 (3.576), and Station 2 (2.9535).

The research results of Kepel et al (2019a) showed that the community structure of seaweeds along the intertidal zone of Mantehage Island had the dominance index value between 0.076-0.122, the diversity index value between 2.42-2.867, the evenness index value between 0.08-0.904, and the richness index value between 21.84-35.85. According to Kepel et al (2019b), the community structure of seaweeds in Minahasa Peninsula in the rainy season has a dominance index value between 0.107-0.154, a diversity index value between 2.242-2.621, an evenness index value between 0.696-0.805, and a richness index value between 2.615-3.216. And the research of Kepel et al

(2020) shows that the community structure of seaweeds in Minahasa Peninsula in the dry season has a dominance index value between 0.17-0.362, a diversity index value between 1.808-2.299, an evenness index value between 0.638-0.829, and a richness index value between 1.583-2.493.

The results of the current study show that the dominance index value was high. The diversity index value was lower than in the intertidal zone of Mantehage Island (Kepel et al 2019a) and in the rainy season on the Minahasa Peninsula (Kepel et al 2019b). On the other hand, the diversity index value was higher than in the dry season on the Minahasa Peninsula (Kepel et al 2020). The evenness index value was low. The richness index value was lower than in the intertidal zone of Mantehage Island, but higher than in the rainy and dry season on the Minahasa Peninsula.

According to Barange & Campos (1991), the existence of species dominance shows the existence of internal competition in resource utilization and conditions of an unbalanced or stressed aquatic environment. A higher diversity index means a lower evenness index.

Correspondence analysis. In this analysis, the total inertia obtained for the 2 axis was 0.5301 (61.9%) and 0.3266 (38.1%) (Table 3). Based on a two-way contingency table with 31 rows and 3 columns containing the abundance of individual macroalgae species, a correspondence analysis map was created. The total inertia for the 2 dimensions is 0.8567 with a contribution from dimension 1 of 0.5301 ($\chi 2$=416.68, 61.88%), and from dimension 2 of 0.3266 ($\chi 2$=256.68, 38.12%). Because there are only 3 columns, interpretation was only carried out on a two-dimensional plot which explains 100% of the variability. Other important information from the correspondence analysis about each row and column category is inertia, absolute contribution and relative contribution. Inertia shows the proportion of a row or column to the total variability. In this case, the row with the largest inertia (*Gracilaria edulis*) represented 13.3% of the total variability, while the column with the largest inertia (Kora-kora) represented 40.6%. Absolute contribution is also important, because it represents the contribution of one row or column to a particular dimension. The column (station) category most responsible for the formation of dimension (axis) 1 is also Kora-kora (absolute contribution of 51.7%). The top formation of dimension 2 is Likupang Marine Station (64.6%). Meanwhile, the line (species) most responsible for the formation of dimension 1 is *Gracilaria edulis* (17.8%), followed by *Ulva reticulata* (14.6%). The top formation of dimension 2 is *Halimeda discoidea* (21.4%), followed by *Halimeda macroloba* (9.3%). *Halimeda opuntia* (relative contribution 0.966), *Galaxaura oblongata* (0.955) and *Actinotrichia fragilis* (0.929) are the exclusive characteristic species for dimension 1, while the exclusive characteristic species for dimension 2 are *Boodlea composita* (0.983), *Halimeda cylindracea* (0.979) and *H. macroloba* (0.957). The exclusive characteristic stations of dimension 1 were Tongkaina (0.855) and Kora-kora (0.789), while for dimension 2 it was Likupang Marine Station (0.646). Dimension 1 (horizontal axis) separates Tongkaina on the positive side of the axis and Kora-kora and Likupang Marine Station on the negative side of the axis. Meanwhile, dimension 2 (vertical axis) separates Tongkaina and Kora-kora on the positive side of Likupang Marine Station on the negative side of the axis. The proximity between species points shows the similarity of their station profiles. In this case, the proximity between the species points *Bornetella sphaerica*, *Caulerpa racemosa*, *Hypnea boergesenii*, *Hypnea musciformis*, *U. reticulata*, *Valonia aegagropila*, *G. edulis*, *Padina australis*, *Halimeda simulans* and *H. opuntia* reveals that these species are characteristic of Tongkeina. Likewise, the closeness of the species points *Chaetomorpha crassa*, *Eucheuma* sp., *Valonia fastigiata*, *Caulerpa sertularioides*, *Turbinaria decurrens*, *Amphiroa fragilissima*, *Avrainvillea erecta* and *Galaxaura oblongata* shows the similarity of station profiles, especially Kora-kora. And the proximity of the species points *Halimeda cylindracea*, *Halimeda tuna*, *H. discoidea*, *Dictyosphaeria versluysii*, *H. macroloba*, *B. sphaerica*, *Neomeris annulata*, *Laurencia papillosa*, *Caulerpa lentillifera*, *Halymenia durvillaei*, *Turbinaria ornata*, *Dictyota dichotoma* and *Actinotrichia fragilis* shows the similarity of the profile of Likupang Marine Station.

Table 3

Inertia and chi-square decomposition

Dimension	*Singular value*	*Inertia*	*Chi-square*	*%*	*Cumulative percentage*
1	0.7281	0.5301	416.6794	61.8808	62.8808
2	0.5715	0.3266	256.6791	38.1192	100.0000
Total		0.8567	673.3580		

Figure 5 represents a dendrogram that classifies seaweed species and Figure 6 represents a dendrogram that classifies the three sampling stations into 2 groups based on the abundance of the 31 species. The two groups are Group I (Tongkaina), and Group II (Likupang Marine Station and Kora-kora). Apparently, the two station groups are related to the type of sediment and density of seagrass.

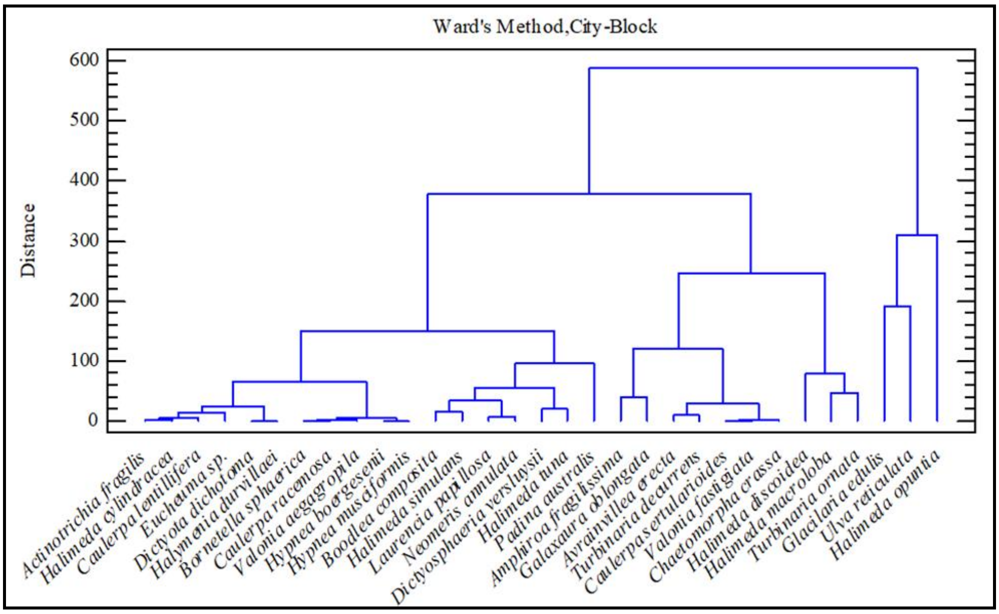

Figure 5. Cluster analysis dendrogram (seaweeds).

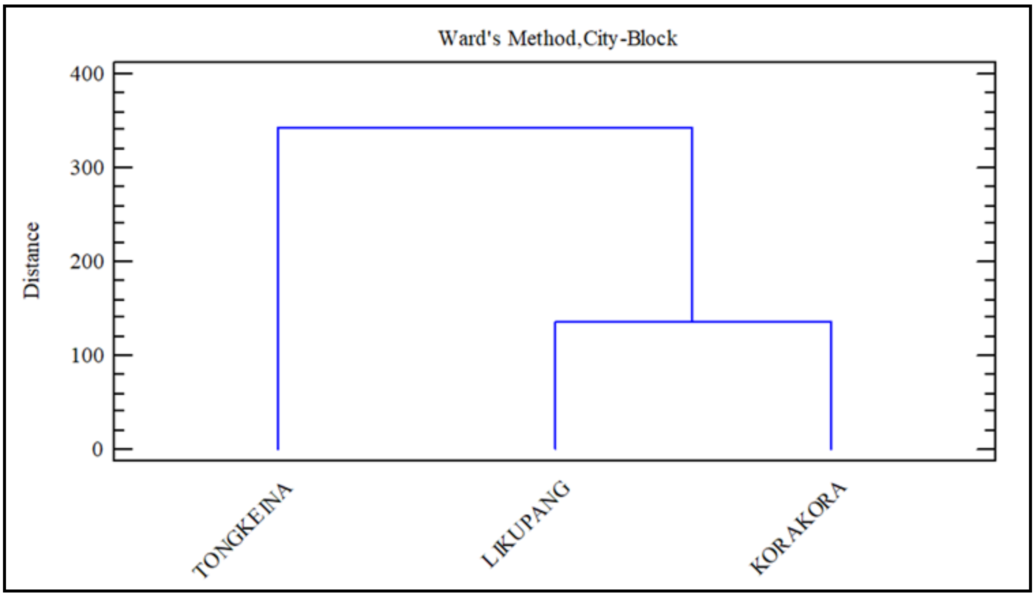

Figure 6. Cluster analysis dendrogram (stations).

Seaweeds are grouped into 3 station groups namely Group I consisting of station 2 (Tongkaina) with mostly muddy sand substrate, and Group II consisting of station 1 and station 3 (Likupang Marine Station and Kora-kora) with rocky substrate and mostly sand substrate respectively.

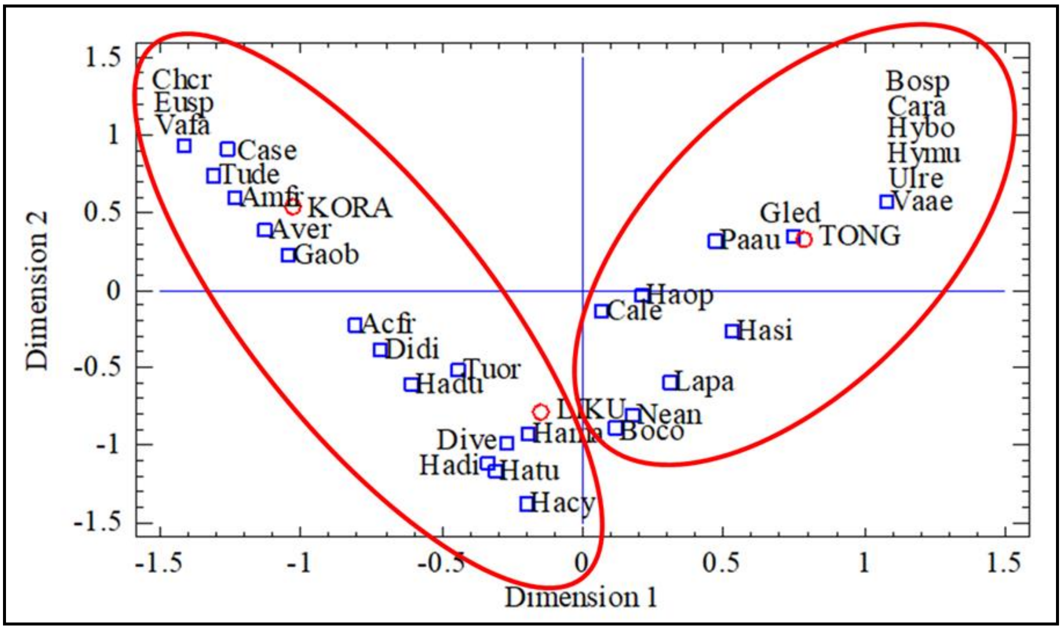

Figure 7. Correspondent map; Acfr - *Actinotrichia fragilis*; Amfr - *Amphiroa fragilissima*; Aver - *Avrainvillea erecta*; Boco - *Boodlea composita*; Bosp - *Bornetella sphaerica*; Cale - *Caulerpa lentillifera*; Cara - *Caulerpa racemosa*; Case - *Caulerpa sertularioides*; Chcr - *Chaetomorpha crassa*; Dive - *Dictyosphaeria versluysii*; Didi - *Dictyota dichotoma*; Eusp - *Eucheuma* sp.; Gaob - *Galaxaura oblongata*; Gled - *Gracilaria edulis*; Hacy - *Halimeda cylindracea*; Hadi - *Halimeda discoidea*; Hama - *Halimeda macroloba*; Haop - *Halimeda opuntia*; Hasi - *Halimeda simulans*; Hatu - *Halimeda tuna*; Hadu - *Halymenia durvillaei*; Hybo - *Hypnea boergesenii*; Hymu - *Hypnea musciformis*; Lapa - *Laurencia papillosa*; Nean - *Neomeris annulata*; Paau - *Padina australis*; Tude - *Turbinaria decurrens*; Tuor - *Turbinaria ornata*; Ulre - *Ulva reticulata*; Vaae - *Valonia aegagropila*; Vafa - *Valonia fastigiata*.

Group I comprises the seaweed inhabitants of Station 2, with mostly muddy sand substrate, consisting of 18 species: *B. composita, B. sphaerica, C. lentillifera, C. racemosa, C. sertularioides, D. versluysii, G. edulis, H. macroloba, H. opuntia, H. tuna, H. boergesenii, H. musciformis, L. papillosa, N. annulata, P. australis, T. ornata, U. reticulata,* and *V. aegagropila.*

Group II comprises seaweed inhabitants of Station 1, with rocky substrate, consisting of 21 species (*A. fragilis, A. fragilissima, A. erecta, B. composita, C. letillifera, C. crassa, D. versluysii, D. dichotoma, G. oblongata, G. edulis, H. cylindracea, H. discoidea, H. macroloba, H. opuntia, H. simulans, H. tuna, H. durvillaei, L. papillosa, N. annulata, P. australis, T. decurrens,* and *T. ornata*), and of Station 3, with mostly sand substrate, consisting of 20 species (*A. fragilis, A. fragilissima, A. erecta, C. letillifera, C. sertularioides, C. crassa, D. versluysii, D. dichotoma, Eucheuma* sp., *G. oblongata, G. edulis, H. discoidea, H. macroloba, H. opuntia, H. tuna, H. durvillaei, P. australis, T. decurrens, T. ornata,* and *V. fastigiata*).

Conclusions. The results of the seaweed inventory in the coastal waters of Likupang Marine Station, Tongkaina and Kora-kora totaled 31 species. The seaweed community structure shows that the dominance index is low, diversity index is medium, evenness index and species richness are high. The highest density of the seaweeds in Stations 1 and 3 was observed for *H. opuntia,* and in Station 2 for *G. edulis.*

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Conflict of Interest. The authors declare that there is no conflict of interest.

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