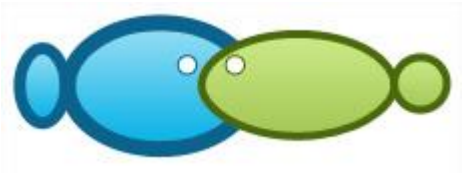

Comparison of seaweed communities in coastal waters with different heavy metals concentrations in Minahasa Peninsula, North Sulawesi, Indonesia

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Abstract. This study was conducted to compare the biodiversity and community structure (species composition, richness, diversity, evenness, dominance and clustering) of seaweeds found in coastal waters at different metal concentrations such as the presence of heavy metals due to small-scale mining activities in the upstream in North Minahasa Regency (Talawaan Bajo), fishing and mariculture activities (Kora-Kora) in Minahasa Regency, and marine tourism activities (Tanjung Merah) in Bitung City. The line transect method was used to identify and quantify the seaweeds abounding the three established stations divided into three transects each station, and each transect divided into ten quadrates. A total of 19 different species of seaweeds were identified in the study area belonging to the classes of Rhodophyceae (Rhodomelaceae, Lithophyllaceae, Galaxauraceae, Gracilariaceae, Cystocloniaceae families), Phaeophyceae (Dictyotaceae, Sargassaceae families) and Ulvophyceae (Ulvaceae, Halimedaceae, Cladophoraceae, Siphonocladaceae, Valoniaceae families). The most abundant seaweed species across the three stations is: *Halimeda opuntia.* The seaweed species identified also have different densities ranging from 0.10 to 12.20 per m^2. *Halimeda opuntia* had the highest density, and *Hypnea boergesenii, Boodlea composita, Dictyota dichotoma, Sargassum crassifolium, Amphiroa fragilissima, Galaxaura rugosa, Actinotrichia fragilis, Turbinaria ornata* and *Laurencia papillosa* had lower densities. Species richness index, diversity index, evenness index and dominance index were calculated to determine the diversity of seaweeds along the study area. Station 2 obtained the highest species richness index and station 1 obtained the lowest species richness index. Station 3 recorded the highest diversity index and station 2 recorded the lowest diversity index. Evenness index was highest at station 1, while the lowest was at station 2. The dominance index was the highest at the station 2, while the lowest at the station 1. The three sampling stations are divided into 3 groups based on an abundance of 19 species of seaweeds. The three groups are Group I (TM1, TM2, TM3), Group II (KK1, KK2, KK3), and Group II (TB1, TB2, TB3). Apparently, the three station groups are related to the type of sediment and presence of seagrass but not due to metal concentrations.

Key Words: aquatic vegetation, species density, richness, diversity, evenness, dominance, clustering.

Introduction. Algae is a diverse group of photosynthetic organisms (Sze 1993). Algae are chlorophyll vegetals (Kaas et al 1992). Seaweeds or macroalgae are aquatic photosynthetic organisms (Pereira 2018). Macroalgae have very varied forms (Gayral & Cosson 1986). The algae forms vary from relative simplicity to more striking complexity (Bold & Wynne 1985). Seaweeds represent an important biotic component of different aquatic ecosystems (Fleurence & Levine 2016). Algae are generally fixed, usually on a solid support (rock, stone, shell etc.), sometimes on other algae (epiphytes) (Ribier & Gonideau 1984). Seaweeds are chlorophyll-containing organisms and they display a photosynthetic process. Seaweeds form different single or multi-celled colonies. They can remain attached to rocks or other supporting material or can be free floating (Se-Kwon 2012). Algae can live on rocks (epilithic), slimes (epipelic), plants (epiphytes), animals

(epizootic), inside rocks (endolithic) or inside plants and animals as symbionts or parasites (Pereira & Neto 2015).

In North Sulawesi waters, there are many species of seaweeds. There are 44 species in Mantehage Island waters (Wattimury et al 2010), 7 species in Mokupa waters (Wowor et al 2015), 15 species in Tongkaina waters, Manado (Kepel et al 2018a), 14 species in Blongko waters, South Minahasa (Kepel et al 2018b), 8 species in Bahoi waters, North Minahasa (Baino et al 2019), 10 species in Kora-Kora waters, Minahasa (Kepel & Mantiri 2019), 45 species in Mantehage Island waters (Kepel et al 2019a), 35 species in Minahasa Peninsula waters in the wet season (Kepel et al 2019b), and 19 species in Minahasa Peninsula waters in the dry season (Kepel et al 2020). In polluted waters by heavy metals, there are studies on *Ulva sp.* (Kepel et al 2018c) and *Halimeda opuntia* (Mantiri et al 2018) in Totok Bay waters and Blongko waters, and *Padina australis* (Mantiri et al 2019a) in Likupang, Manado Bay, Talawaan Bajo and Ratatotok waters. These waters are polluted with heavy metals. There are studies of antioxidant bioactivity and chlorophyll concentration in green algae *Halimeda opuntia*, *Halimeda taenicola*, and *Ulva prolifera* from Totok Bay (Mantiri et al 2019b). Seaweeds are widely used as bioindicators to monitor the bioavailable concentrations of contaminants such as heavy metals and to assess the environmental pollution status (Rodríguez-Figueroa et al 2009; Karthick et al 2012; Chakraborty et al 2014). Algae function as a bioremediator. It is shown in *Halimeda opuntia* cells via TEM analysis that metals are detected, but the algae still remains alive (Mantiri et al 2018).

The present study was conducted to identify the seaweed biodiversity and determine their community structure in coastal waters, and their heavy metals concentrations, in Minahasa Peninsula, North Sulawesi, Indonesia.

Material and Method

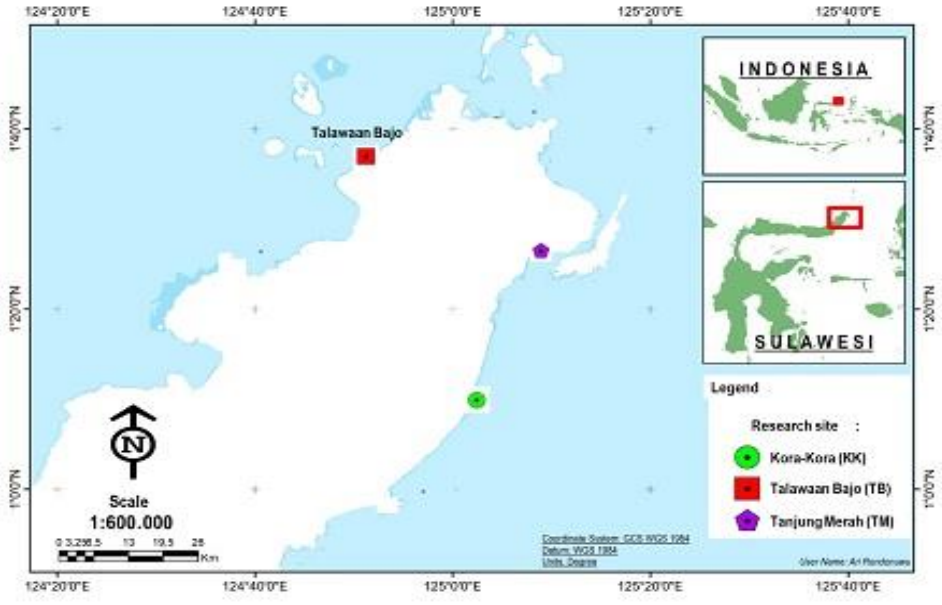

Figure 1. Map of research location in Minahasa Peninsula.

Study area. This research was conducted from April 2019 to February 2020. The research locations were in the coastal waters of Tanjung Merah, Matuari Sub-District, Bitung City (station 1), coastal waters of Kora-Kora, East Lembean Sub-District, Minahasa Regency (station 2), and in the estuary of Talawaan River, Talawaan Bajo Village, Wori Sub-District, North Minahasa Regency (station 3), North Sulawesi Province, Indonesia (Figure 1). Each station was divided into 3 transects. Data collection of seaweeds was carried out in 3 points, namely station 1 with 3 transects named TM1,

TM2, TM3; station 2 with 3 transects named KK1, KK2, KK3; and station 3 with 3 transects named TB1, TB2, TB3. In station 1 there was a dense seagrass meadow, with muddy substrate and this area has marine tourism activities. In station 2 there was a less dense seagrass meadow from near the coast toward the sea, with muddy substrate and fragments of dead coral and this area has fishing and mariculture activities. In station 3 there was a muddy substrate and upstream there is a small-scale mining site, which discharges waste into the river, that finally reaches the estuary of Talawaan River.

Seaweed sampling techniques. This research was done using the line transect method with quadratic sampling technique (Krebs 1999). The placement of transects in each location is done by using 3 lines of 100 m drawn perpendicular to the coastline, with the assumption that the community is evenly distributed. The distance between transects is 5 m and the distance between squares is 10 m. The sample is calculated and taken at the lowest ebb with the square size used to retrieve data of 1x1 m^2.

The first square is placed near the shore, where the first seaweeds are found and the last square in the furthest part where seaweeds grow. Likewise, the other nine points are determined systematically between the first square to the last predetermined square, which is random by first specifying the transect length, then divided by the sum of squares and the results are randomized, based on the square size that can enter the results of the calculation. Determination of individual seaweed strands contained in the square is done by counting the strands of seaweeds.

Sediment sampling techniques. Sediment was also collected from the seaweed collection points. We used a PVC pipe to collect sediment from the sea floor. The collected sediment samples were placed in storage containers. For metal analysis, following the American Public Health Association (APHA) (2012) and United States Environmental Protection Agency (USEPA) (2011) guidelines, 10 g of sediment were needed. Seawater was collected in a glass container, from a depth of 30 to 40 cm below the water surface. As much as 100 ml of seawater was needed for the metal analysis. The seawater was previously filtered through 0.45 µm filter paper, then mixed with nitric acid (HNO_3) and ammonium pyrrolidine dithiocarbamate (APDC).

Sample analysis. Metal content of sediments was analyzed following the American Public Health Association (APHA) (2012) and United States Environmental Protection Agency (USEPA) (2011) protocols. Metal detection was done using ICP-OES (Inductively Coupled Plasma-Optical Emission Spectrometry). The sediment concentration of metal was compared with the standard of Canadian Council of Ministers of the Environment (CCME) (2002). Cadmium (Cd) and mercury (Hg) concentrations were compared with the concentrations from the Indonesian National Standard (SNI No. 7387 – 2009). Chromium (Cr) concentrations are not indexed by the Indonesian National Standard.

Sample identification. Identification of samples was done using the books of Trono (1997), Trono & Ganzon-Fortes (1988), and Calumpong & Meñez (1997).

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

Species Density = Number of individuals per species/the area of the sample

Richness Index. The richness index (R) was calculated using the following formula (Ludwig & Reynolds 1988), where S is the total number of species in a community:

$$R = \frac{(S-1)}{\ln(n)}$$

Diversity index. The Shannon Wiener's index (H') is calculated using the following formula (Ludwig & Reynolds 1988), where ni is the number of individuals of its species and N is total number for all species (S) in the population:

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

Evenness index. The evenness index (E) is calculated using the following formula (Ludwig & Reynolds 1988), where H' is the evenness index and H' max is maximum value:

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

Dominance index. The dominance index is calculated using the following formula (Odum 1971), and ni is the number of individuals in a species and the total number for all species is N:

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

Correspondence analysis. Correspondence analysis (CA) provides a geometric presentation in which the studied variable is mapped into points on the cross axis. This 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 get the correct correspondence or relationship between the two variables studied (species and stations). The notations used are:

$k = \sum\sum k_{ij}$ = total amount of individuals
$f_{ij} = k_{ij}/k$ = 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 following 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 given by 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 in the two corresponding groups are calculated to interpret certain axes in the CA. The data display in the two-way contingency table through CA is done using the STATGRAPHICS Centurion packaging program through the Correspondence Analysis menu selection.

Results and Discussion

Metal concentration in sediment. Metal content analyses determined that sediment from station 1, station 2 and station 3 had the next range of metal concentrations: cadmium 0.04-0.45 ppm, chromium <0.2-4.90 ppm, and mercury <0.005-0.37 ppm (Table 1).

Table 1

Metal concentration in sediment

Metal	*Station 1 (ppm)*	*Station 2 (ppm)*	*Station 3 (ppm)*	*CCME, 2002 (ppm)*
Cadmium (Cd)	0.04	0.28	0.45	0.70
Chromium (Cr)	<0.20	1.80	4.90	52.30
Mercury (Hg)	<0.05	<0.005	0.37	0.13

The concentration of all metals in station 3 was the highest due to a small-scale mining activities upstream, that removes waste into the river so that it finally reaches the estuary of Talawaan River. Cadmium and chromium have been detected at station 2 although the waters are far from mining activities. It is suspected that their presence is due to the natural content of both elements in local rocks. Instead, at station 1 the concentration of all metals was very low. In general, the concentrations of cadmium and chromium in all stations were still lower than the values provided by CCME (2002). At station 3, the concentration of mercury was higher than the maximum presented by CCME (2002). For example, cadmium concentration in sediment is 4.71 ppm at Totok Bay, above the CCME standard (2002). Nasprianto et al (2019) also state that this bay waters are polluted with heavy metals.

Minahasa peninsula is recognized as a mineralized region of important economic metals such as gold, iron etc. (Suprapto 2006; Maulana et al 2013). Heavy metals are stable in the lithosphere compartment (Paasivirta 1991), and the conversion of lithosphere by human activity, through mining, changes the heavy metal properties by oxidation reaction and potentially determine contamination of the environment by rain run off (Thiele et al 2014). In this research, we identified traditional gold mining without water treatment detoxification upstream on the Talawaan River. Residual waste is dicharged into Talawaan River and is finally accumulated by biota and sedimented in the estuary.

In natural waters heavy metals come from several sources and natural processes such as rivers, sea floor leaching through interstitial water, rock abrasion, biodegradation of organic materials and from the atmosphere (Paasivirta 1991; Rombke & Moltman 1996). Mining is an anthropogenic activity and can produce heavy metal waste (Campbell & Tessier 1996; Goh & Chou 1997). Presence of heavy metals in water has broad implications on aquatic organisms, macroalgae and intertidal plants such as mangroves (Paulus et al 2015; Mantiri et al 2019a). Metals precipitate amongst sediments, and the dissolved forms are stable in water (Rombke & Moltman 1996). The dissolved heavy metals have the consequence of high bioaccumulation in organisms, by biological magnification pathway (Allen & Janssen 2006).

High concentrations of metals on the sea floor does not automatically determine high concentrations in macroalgae (Campbell & Tessier 1996; Brown & Markich 2000; Riba et al 2003). Heavy metals transfer to the organism through dietary route and non-dietary route, where the dietary route is called bioaccumulation and the non-dietary route is called biosorption (Rombke & Moltman 1996; Hashim & Chu 2004; Partiban et al 2010; Ibrahim et al 2016; Handhani et al 2017). In Talawaan River estuary, heavy metals accumulated in macroalgae, are in different quantities and distribution, depending on the macroalgae species. The arsenic concentration in *Padina australis* (1.3-2.1 ppm) was higher than in sediment (<1 ppm) (Mantiri et al 2019a). This shows biomagnification of arsenic concentration in this seaweed. Results of this research in Talawaan River estuary show bioaccumulation and biomagnification of heavy metals.

The concentrations of chromium in the sediments of Totok Bay waters were generally higher (Cr 10.9 ppm) compared to those from Blongko waters (Cr<0.2 ppm). The concentration of chromium (Cr) in sediment from both Totok Bay and Blongko waters was below the standards set by the Canadian Council of Ministers of the Environment (CCME 2002), respectively 52.3 ppm (Mantiri et al 2018). In this research, the range of chromium concentrations in all stations was <0.20-4.90 ppm. Totok Bay had a higher concentration of chromium, compared to the other locations in this research, because of a small-scale mining site, that removes waste into the river and that finally reaches the estuary of Totok Bay. However, the concentration of chromium is lower in Blongko waters, than the results of this research, because there is no mining activity.

Manado Bay had mercury concentrations of <0.05 ppm in the dry season, but during the rainy season the concentrations rose to 0.2 ppm. Totok Bay had higher concentrations than the standard in both seasons, higher in the dry season than in the rainy season, 3.2 ppm (dry season) and 1.55 ppm (rainy season). Likupang waters had lower concentrations in both seasons, <0.05 ppm (Mantiri et al 2019a). In this research, the range of mercury concentrations in all stations was <0.005-0.37 ppm. This shows that the Totok Bay had a higher concentration of mercury compared to the results of this research because of small-scale mining activity. However, the concentration of mercury in Manado Bay and Likupang is lower, than the results of this research, because there is no mining activity. The cadmium concentrations in three locations, station 1, 2, and 3 (Table 1), are under the standard of CCME (2002), except station 3, where the mercury concentration was higher than the maximum presented by CCME (2002). The higher mercury concentration in station 3 is due to mining activities.

Species composition. There were 19 species of seaweeds identified from 16 families belonging to Rhodophyceae, Phaeophyceae and Ulvophyceae classes (Table 2).

Table 2

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 rugosa*
4				*Galaxaura apiculata*
5				*Actinotrichia fragilis*
6		Gracilariales	Gracilariaceae	*Glacilaria edulis*
7				*Glacilaria salicornia*
8		Gigartinales	Cystocloniaceae	*Hypnea boergesenii*
9	Phaeophyceae	Dictyotales	Dictyotaceae	*Padina australis*
10				*Padina minor*
11				*Dictyota dichotoma*
12		Fucales	Sargassaceae	*Turbinaria ornata*
13				*Sargassum crassifolium*
14	Ulvophyceae	Ulvales	Ulvaceae	*Ulva prolifera*
15		Bryopsidales	Halimedaceae	*Halimeda macroloba*
16				*Halimeda opuntia*
17		Cladophorales	Cladophoraceae	*Chaetomorpha crassa*
18		Siphonocladales	Siphonocladaceae	*Boodlea composita*
19			Valoniaceae	*Valonia aegagropila*

Density parameter and number of species. The density of seaweeds found along the intertidal zone of station 1, transect 1 (TM1) is shown in Figure 2. In TM1, there were 5 species having a density of 0.10-2.60 ind./m², where *D. dichotoma* had the highest density of 2.60 ind./m², while *H. boergesenii* had the lowest density of 0.10 ind./m². Station 1 transect 2 (TM2) is shown in Figure 3. There were 6 species having a density of

0.10-1.70 ind./m², where *H. opuntia* had the highest density of 1.70 ind./m², while *B. composita* had the lowest density of 0.10 ind./m². Station 1 transect 3 (TM3) is shown in Figure 4. There were 5 species having a density of 0.10-2.70 ind./m², where *A. fragilissima* had the highest density of 2.70 ind./m², while *D. dichotoma* had the lowest density of 0.10 ind./m².

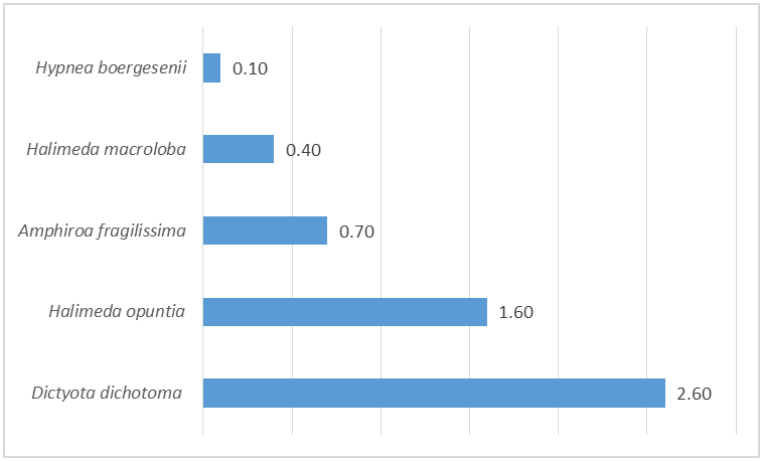

Figure 2. Density of seaweeds in TM1.

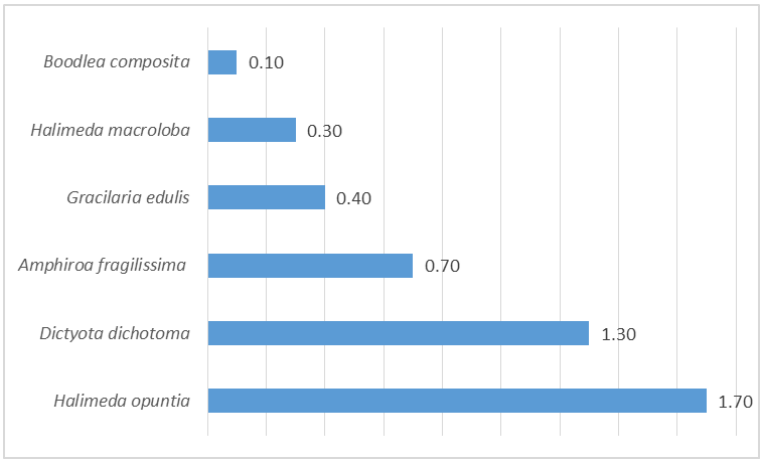

Figure 3. Density of seaweeds in TM2.

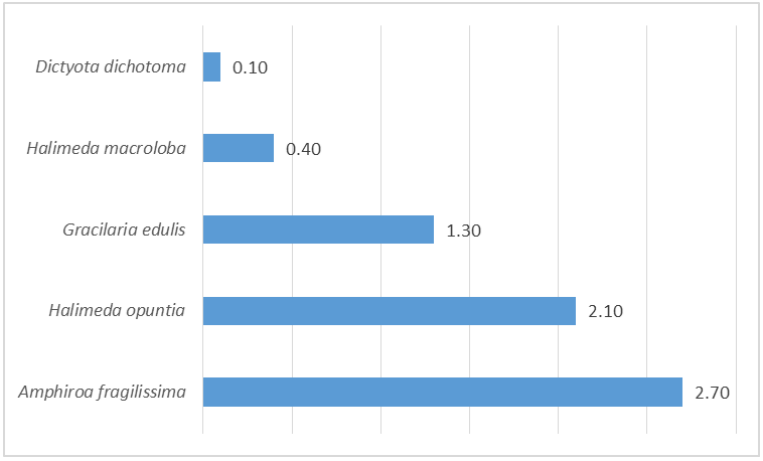

Figure 4. Density of seaweeds in TM3.

In station 2 transect 1 (KK1) (Figure 5), there were 10 species with a density of 0.10-11.00 ind./m², where *H. opuntia* had the highest density of 11.00 ind./m², while *S. crassifolium* and *A. fragilissima* had the lowest densities of 0.10 ind./m². Station 2

transect 2 (KK2) is shown in Figure 6. There were 9 species having a density of 0.10-7.70 ind./m², where *H. opuntia* had the highest density of 7.70 ind./m², while *G. rugosa* had the lowest density of 0.10 ind./m². Station 2 transect 3 (KK3) is shown in Figure 7. There were 10 species having a density of 0.10-12.20 ind./m², where *H. opuntia* had the highest density of 12.20 ind./m², while *S. crassifolium* and *H. boergesenii* had the lowest densities of 0.10 ind./m².

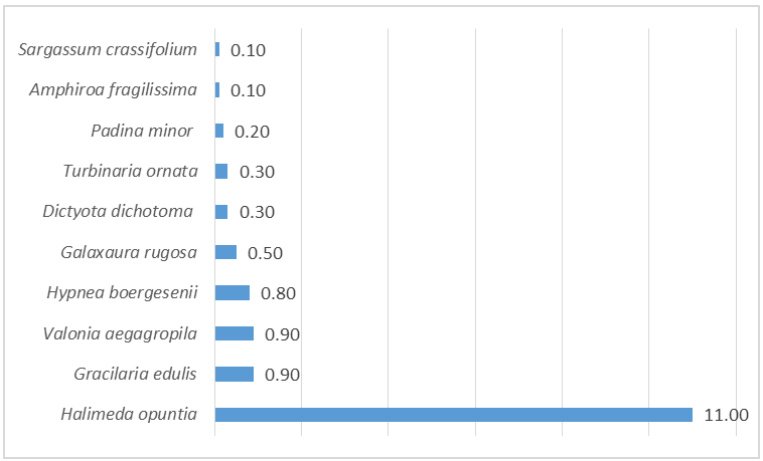

Figure 5. Density of seaweeds in KK1.

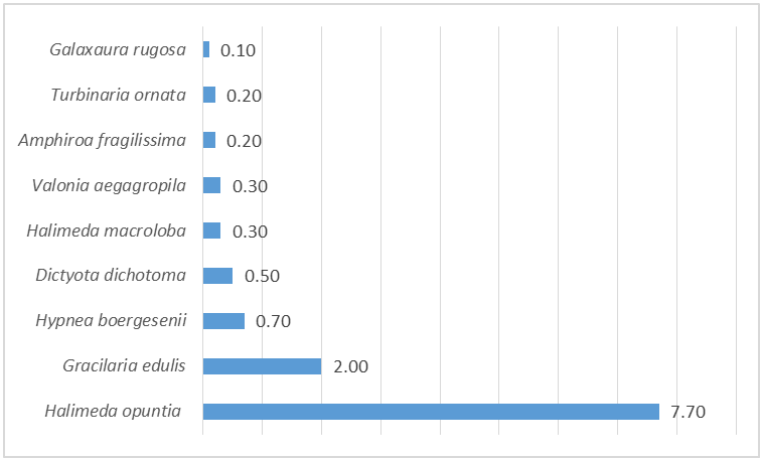

Figure 6. Density of seaweeds in KK2.

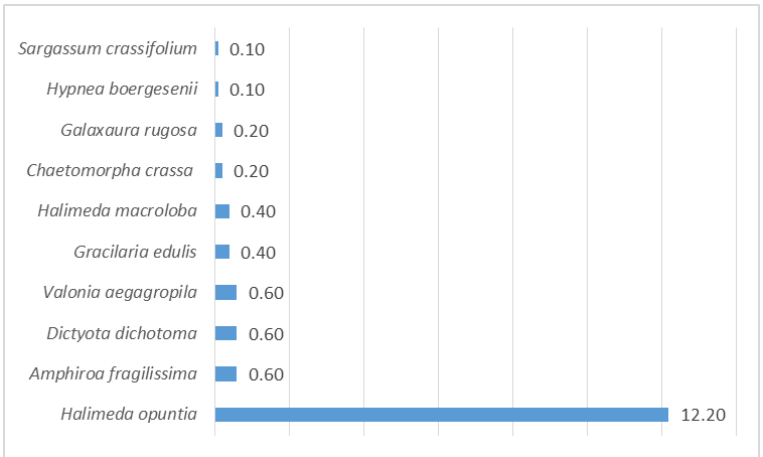

Figure 7. Density of seaweeds in KK3.

In station 3 transect 1 (TB1) (Figure 8), there were 8 species having a density of 0.10-5.00 ind./m², where *A. fragilissima* had the highest density of 5.00 ind./m², while *A.*

fragilis had the lowest density of 0.10 ind./m². Station 3 transect 2 (TB2) is shown in Figure 9. There were 9 species having a density of 0.10-4.80 ind./m², where *U. prolifera* had the highest density of 4.80 ind./m², while *T. ornata* had the lowest density of 0.10 ind./m². Station 3 transect 3 (TB3) is shown in Figure 10. There were 8 species having a density of 0.10-4.70 ind./m², where *G. edulis* had the highest density of 4.70 ind./m², while *T. ornata* and *L. papillosa* had the lowest densities of 0.10 ind./m².

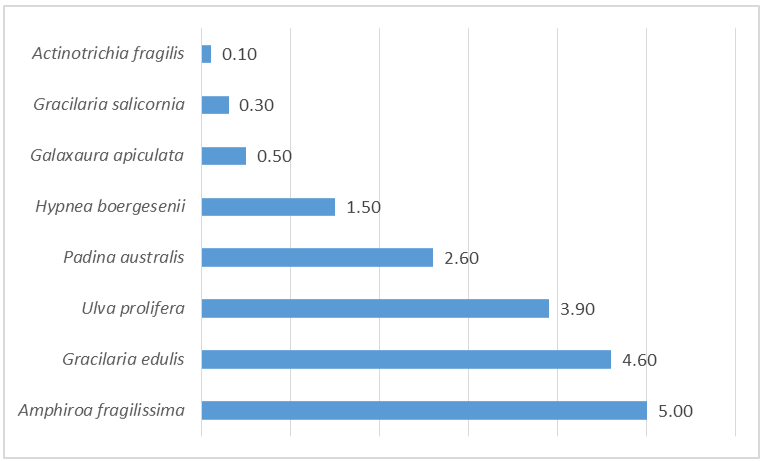

Figure 8. Density of seaweeds in TB1.

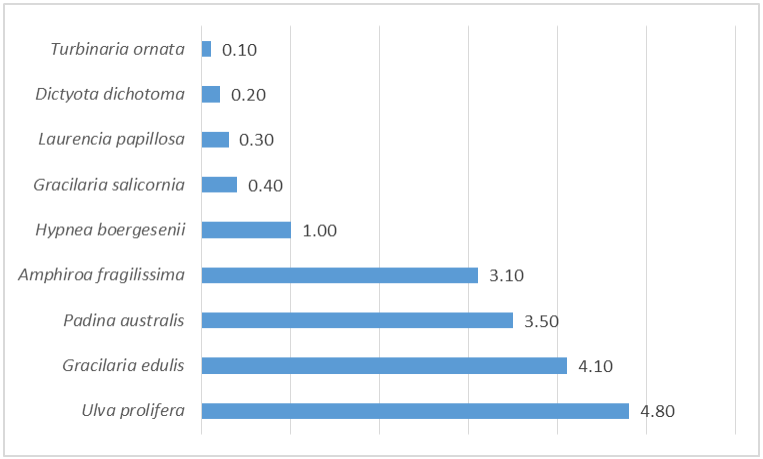

Figure 9. Density of seaweeds in TB2.

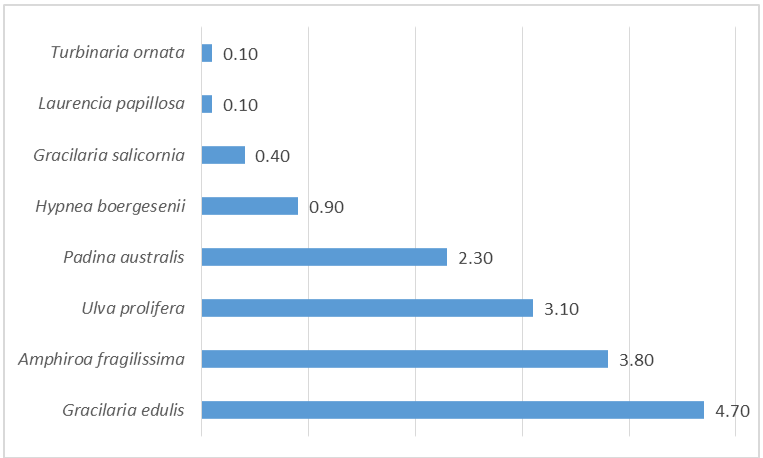

Figure 10. Density of seaweeds in TB3.

Richness index, diversity index, evenness index and dominance index. Based on the calculation of several ecological indices from seaweeds at each transect in 3 stations,

the values of the richness index (R), diversity index (H´), evenness index (E), and dominance index (D) are shown in Table 3.

Table 3

Value of seaweed community indices

Station/Transect	*D*	*H´*	*E*	*R*
Station 1				
Transect TM1	0.227	1.244	0.773	1.003
Transect TM2	0.165	1.496	0.835	1.313
Transect TM3	0.203	1.283	0.797	0.955
Station 2				
Transect KK1	0.516	1.115	0.484	1.794
Transect KK2	0.435	1.242	0.565	1.671
Transect KK3	0.595	0.932	0.405	1.787
Station 3				
Transect TB1	0.182	1.700	0.818	1.341
Transect TB2	0.216	1.724	0.784	1.549
Transect TB3	0.211	1.640	0.789	1.390

Based on the results in Table 3, it appears that the highest species richness index value was in station 2 (transect KK1), with a value of 1.794 and the lowest value was at station 1 (transect TM3), with a value of 0.955. In general, the richness index value in the station 2 was the highest (1.671-1.794). The richness index value at station 1 should be higher than at station 2, because the concentration of heavy metals (cadmium and chromium) at station 1 is lower than at station 2, but in reality we see the opposite. We observe that these heavy metal concentrations do not significantly affect the richness index value. It seems that seaweeds play a role as bioremediator. To our knowledge, there has been no research in this region regarding the influence of heavy metal concentrations on the richness index value.

The diversity index value in these stations show that station 3 (transect TB2) had the highest diversity value, of 1.724, while the lowest diversity value was at station 2 (transect KK3), of 0.932. In general, the diversity index value at station 3 was the highest (1.640-1.724). However, the concentrations of all metals (cadmium, chromium and mercury) at station 3 were the highest, while the seaweed diversity was also the highest. So, heavy metal concentrations do not affect the seaweed diversity. Seaweeds can survive in waters with different heavy metal pollution levels and serve a bioremediatory purpose. Seaweeds possess high absorption capacities for heavy metal ions (Yun et al 2001). The cell walls of seaweeds are composed of polysaccharides, proteins, and lipids, which contain functional groups with high affinity to heavy metal ions, such as hydroxyl, carboxylate, and amino groups (Park et al 2005). Seaweeds are known for their high absorption capacity for heavy metal ions (Volesky 2003). Seaweed biomass has been found to possess the highest absorption capacities, even more than that of activated carbon and natural zeolite (Herrero et al 2006; Cochrane et al 2006). The absorption of heavy metal ions by seaweed biomass is affected by many factors such as pH, temperature, initial heavy metal ion concentration, contact time, and most importantly, the type of seaweeds involved. Volesky (2003) has mentioned the absorption of heavy metal ions by seaweed biomass takes place via a number of different mechanisms, including complexation, sequestration, ion exchange, physical adsorption, redox reaction etc., with the absorption capability mostly determined by the composition and structure of seaweed cell walls that are mainly composed of polysaccharides, proteins, and lipids.

The evenness index value was the highest at station 1 (transect TM2), with a value of 0.835, while the lowest value was at station 2 (transect KK3), of 0.405. In general, the evenness index value at station 1 was the highest (0.773-0.835). However, the concentrations of all metals (cadmium, chromium and mercury) in station 1 were the lowest and the seaweed evenness was the highest. Heavy metal concentrations were in

line with seaweed evenness index values. It means that the low concentration of heavy metals at station 1 allows for a more equitable distribution of individuals for each species of seaweed.

The dominance index value was the highest at station 2 (transect KK3), with a value of 0.595, while the lowest was at station 1 (transect TM2), with a value of 0.165. In general, the dominance index value at station 2 was the highest (0.435-0.595). However, the concentrations of all metals (cadmium, chromium and mercury) at station 3 were the highest, while the seaweed dominance was not the lowest. It shows that heavy metals do not determine certain species of seaweed to dominate other species of seaweed. There are several examples of seaweed that can survive in waters polluted with heavy metals, such as *Ulva sp.* (Kepel et al 2018c), *H. opuntia* (Mantiri et al 2018), and *P. australis* (Mantiri et al 2019a). These seaweeds take the role of bioremediator.

Correspondence analysis. Correspondence Analysis (CA) is carried out based on abundance data in two-way contingency tables, namely 19 rows of species and 9 sub-station columns. Station 1 had a dense seagrass meadow with muddy substrate.

The total inertia for the eight axes in this analysis was the highest at 0.7298 (62.1%), and the lowest at 0.0036 (0.3%), with a total of 100% (Table 4).

Table 4

Inertia and chi-square decomposition

Dimension	*Singular value*	*Inertia*	*Chi-Square*	*%*	*Cumulative Percentage*
1	0.8543	0.7298	805.6782	62.1042	62.1042
2	0.5302	0.2811	310.2968	23.9187	86.0229
3	0.2679	0.0718	79.2451	6.1085	92.1313
4	0.1793	0.0322	35.5080	2.7371	94.8684
5	0.1576	0.0248	27.4300	2.1144	96.9828
6	0.1300	0.0169	18.6541	1.4379	98.4207
7	0.1223	0.0150	16.5078	1.2725	99.6932
8	0.0600	0.0036	3.9804	0.3068	100.0000
TOTAL		1.1751	1,297.300		

Figure 11 is a dendrogram that classifies seaweed species. There were three groups of species, Group I (*H. opuntia*), Group II (*A. fragilissima, G. edulis, P. australis, U. prolifera*), and Group III (*A. fragilis, B. composita, P. minor, C. crassa, S. crassifolium, G. apiculata, G. salicornia, L. papillosa, G. rugosa, T. ornata, V. aegagropila, H. macroloba, H. boergesenii, D. dichotoma*).

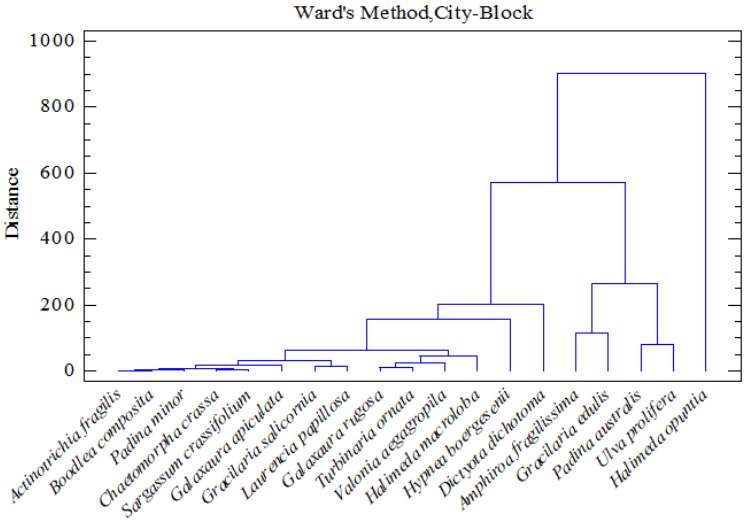

Figure 11. Cluster analysis dendrogram (seaweeds).

Figure 12 is a dendrogram that classifies the three sampling stations into groups based on the abundance of 19 species. The three groups are Group I (Tanjung Merah), Group II (Kora-Kora), and Group III (Talawaan Bajo). Apparently, in Group I each transect TM1, TM2, and TM3 had relatively the same dense seagrass meadow with muddy substrate. In Group II each transect KK1, KK2, and KK3 had relatively the same less dense seagrass meadow from near the coast toward the sea with muddy substrate and fragments of dead coral. In Group III each transect TB1, TB2, and TB3 had relatively the same muddy substrate.

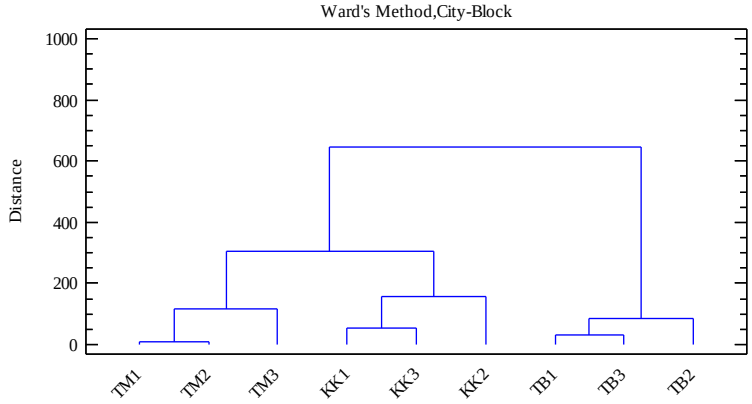

Figure 12. Cluster analysis dendrogram (transects).

Overall, seaweed is grouped into three transect groups namely Group I consisting of station 1 (transect TM1, TM2, TM3) with muddy substrate and dense seagrass meadow, Group II consisting of station 2 (transect KK1, KK2, KK3) with muddy substrate and fragments of dead coral and less seagrass meadow and Group III consisting of station 3 (transect TB1, TB2, TB3) with muddy substrate (Figure 13).

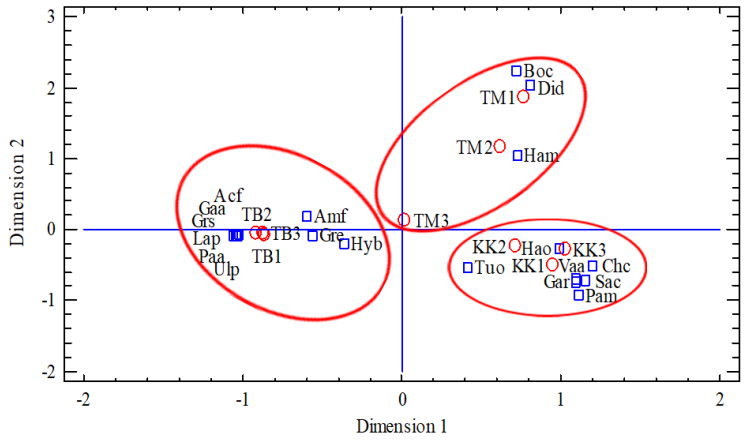

Figure 13. Correspondent map. Note: *Acf (Actinotrichia fragilis), Amf (Amphiroa fragilissima), Boc (Boodlea composita), Chc (Chaetomorpha crassa), Did (Dictyota dichotoma), Gaa (Galaxaura apiculata), Gar (Galaxaura rugosa), Gre (Gracilaria edulis), Grs (Gracilaria salicornia), Ham (Halimeda macroloba), Hao (Halimeda opuntia), Hyb (Hypnea boergesenii), Lap (Laurencia papillosa), Paa (Padina australis), Pam (Padina minor), Sac (Sargassum crassifolium), Tuo (Turbinaria ornata), Ulp (Ulva prolifera), Vaa (Valonia aegagropila)*.

Group I was transect TM1, TM2 and TM3 (station 1), with characteristics of muddy substrate and dense seagrass meadow consisting of 3 species: *Boodlea composita, Dictyota dichotoma, Halimeda macroloba.*

Group II was transect KK1, KK2 and KK3 (station 2), with the characteristics of muddy substrate and fragments of dead coral and less seagrass meadow consisting of 7

species: *Chaetomorpha crassa, Galaxaura rugosa, Halimeda opuntia, Sargassum crassifolium, Padina minor, Turbinaria ornata, Valonia aegagropila.*

Group III was transect TB1, TB2 and TB3 (station 3), with characteristics of muddy substrate without seagrass meadow consisting of 9 species: *Actinotrichia fragilis, Amphiroa fragilissima, Galaxaura apiculata, Gracilaria edulis, Gracilaria salicornia, Hypnea boergesenii, Laurencia papillosa, Padina australis, Ulva prolifera.*

From the results we notice that the occurrence of seaweed groups on the same station is due to the type of subtrate, not determined by the concentration of heavy metals. This is due to seaweed functioning as a bioremediator. Seaweed presents high ability to absord metals and heavy metals since they have cytoplasmic cell walls that are able to bind the metal ions (Bachtiar 2007). According to Hashim et al (2004), Ibrahim et al (2016), Roy & Anantharaman (2017), in polluted areas seaweed can play a role as an environmental bioremediator with the ability to absorb heavy metals or known as biosorption processes.

Conclusions. The results of the seaweed inventory in the coastal waters at different metal concentrations of Minahasa Peninsula totaled 19 species. The seaweeds community structure shows that the values of diversity, evenness, dominance, and species richness is not influenced by metal concentrations. Bioaccumulation and biomagnification of heavy metals occurs among seaweeds. The bioremediatory role of seaweeds is the high absorption capacity for heavy metal ions. The highest density of the seaweeds was *H. opuntia*, while the lowest density respectivey was *H. boergesenii, B. composita, D. dichotoma, S. crassifolium, A. fragilissima, G. rugosa, A. fragilis, T. ornata* and *L. Papillosa.*

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