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Biomonitoring of Mercury in Seagrass Ecosystems by Periphyton Epiphyte Algae *Stigeoclonium* sp. in the Estuary of Talawaan Bajo North Minahasa, Indonesia

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ABSTRACT

Periphyton that lives attached to seagrass leaves is generally a source of autochthonous energy in the waters and has a major role in the food chain system that supports the primary productivity of seagrass beds. The aim of the current study was to study the extent to which mercury (Hg) levels affect the ecosystem by looking at Hg accumulation in the periphyton. This study used the method of species composition analysis, the density of epiphytic periphyton algae on seagrass, and analyzed the level of pollution in the Talawan Bajo estuary waters based on the bioaccumulation of mercury content in the periphyton and analyzed the periphyton as a bioindicator of the level of Hg pollution in the waters. The first stage was to identify the types of seagrass and periphyton and analyze the composition and density; diversity index, uniformity and dominance of periphyton. The second stage of this study included observation of the accumulation of heavy metal Hg on a laboratory scale and visualization of periphyton cells using TEMcell. Based on the results of the analysis, it was shown that the environmental conditions of the Talawaan Bajo estuary were polluted by heavy metal Hg because the Hg content accumulated in seagrass and periphyton exceeded the quality standards for aquatic biota. It was concluded that the environmental conditions of the Talawaan Bajo estuary were contaminated with heavy metal Hg because the Hg content accumulated in seagrass and periphyton exceeded the quality standards for aquatic biota. Hg contamination in aquatic ecosystems affects the life of biota in the environment, especially damage to tissue structures.

Keywords: periphyton, mercury, Talawaan Bajo, manado, biomonitoring.

INTRODUCTION

The results of industrialization and population concentration in large cities have resulted in the accumulation of large amounts of waste (Simonis, 1994). Waste is liquid waste from a community environment where the main component is air and approximately 0.1% in the form of solid objects consisting of organic and inorganic substances (Mahida, 1992). Waste comes from various anthropogenic sources including industrial waste, garbage, urban runoff, waste processing plants, boat activities, agricultural fungicide flows, household waste sites and mining activities (Tamilselvan, 2012).

As is the case in the Talawaan Bajo estuary, especially the water conditions at the three research locations (location I Talawaan River flow, location II Talawaan Bajo estuary and location III sea waters in front of Talawaan Bajo Village), overall are still quite good, except for the pH value. at location I which is slightly lower than other locations (Joseph, 2001). Meanwhile, the concentration in the sea waters around the mouth of the

Talawaan River up to a distance of 100 meters towards the sea has been contaminated with mercury metal which is indicated to have exceeded the water quality standard limit. The results of the study stated that the presence of mercury in the water ranged from 0.0034–0.0037 ppm. This condition is caused by the gold mining activities of the people of Tatelu Village, which since 1950 until now the gold processing uses mercury metal (Ngangi, 2000). The Tatelu mining area is a natural resource management area, especially gold, which is carried out by several villages in part of the Dimembe District such as Talawaan, Tatelu, Warukapas, Tatelu Rondor and Wasian Villages. The five villages in the Tatelu area are part of the Talawaan River Basin.

Periphyton that lives attached to seagrass leaves is generally a source of autochthonic energy in waters and has a major role in supporting the primary productivity of seagrass beds in addition to the seagrass community itself, so that in total it will increase the primary productivity of the seagrass ecosystem. Periphyton has a very important role in the food chain in the seagrass ecosystem, where periphyton is a natural food for other organisms at higher trophic levels. In addition to playing an important role in primary productivity, periphyton is also useful as an ecological indicator (Chindah et al., 2009) and the level of water pollution, and can respond to changes in aquatic environmental conditions (Zulkifli, 2000). Studies on seagrass in Indonesia, especially in Bangka Belitung have been reported (Rosalina et al., 2019a).

Tatelu community gold mining activities are feared to affect the seagrass ecosystem in the Talawaan Bajo estuary due to the uncontrolled use of heavy metal Hg. Given the above, the goal of the current study is to study to what extent the Hg levels affect the ecosystem by looking at the accumulation of Hg in the periphyton.

MATERIAL AND METHOD

Research location

The research location at this stage was carried out in the Talawaan Bajo Estuary, North Minahasa Regency, North Sulawesi Province. The water profile of the Talawaan Bajo estuary starts from the coastline in the form of mangroves, and in various areas it is overgrown with seagrass and there are stretches of coral reefs to a depth of about 5–10 m at high tide with a slightly sloping bottom profile. The research was conducted in June – December 2023.

Data analysis

Biomass for Mercury (Hg) content analysis

Seagrass sampling for biomass calculation was carried out on predetermined plots based on the method described in English et al., (1994). This method was chosen because it can minimize damage to seagrass due to plant removal. The seagrass samples that had been obtained were washed to clean them from seawater and epibiota dirt and put in plastic bags and put in a cool box that had been filled with ice cubes and the samples were taken to the laboratory for analysis (Herawati, 2008).

Sediment sampling for mercury (Hg) content analysis

Sediment sampling was carried out at the location where seagrass research samples were taken. Sediment samples were taken using flexi glass with a diameter of 5.08 cm and a height of 35.2 cm. At each sampling station, sediment was taken once at a depth of ± 10 cm. Sediment samples were then put into a cleaned plastic bag and put into a box with cold conditions during transportation until the analysis stage. Sediment analysis includes the type of substrate and its total carbon content (Kiswara, 2010).

Periphyton

Phytophyton sampling method on seagrass

Periphyton samples were taken at each transect line for all points. At each selected point, periphyton samples were taken from seagrass that was present when the water receded during the day. The selected seagrass leaves were undamaged seagrass leaves, then placed in a plastic bag that had been labeled and preservative.

In the Laboratory, periphyton samples were taken from various seagrass leaves by scraping the surface of the seagrass leaves, then doused with distilled water to ensure that no periphyton was left behind. The periphyton samples obtained were then placed in a labeled sample bottle and diluted with distilled water to a volume of 100 ml, then given 4% formalin preservative. Periphyton observations were carried out under a binocular microscope with a magnification of 400 times using the Luckey Drop method and identification was based on Biggs and Kilroy (2000) and the identification books of Davis (1955), Presscot (1959), and Yamaji (1979).

RESULTS AND DISCUSSION

Aquatic environmental conditions

Observations based on land use at each location describe the overall aquatic environmental conditions in the Talawaan Bajo Estuary, North Sulawesi. Location I is an area close to local settlements and is a place used for anchoring fishing boats. The environmental conditions at Location II contain mangroves which are nutrient trapping areas. Location III is the location closest to the estuary.

The observed water clarity in the waters of the Talawaan Bajo Estuary is 100%, which means that at the observation location, irradiation still occurs to a certain depth. Based on these data, it can be seen that the waters of the Talawaan Bajo Estuary are shallow and clear waters because light can enter to a certain depth. Shallow water conditions affect the life of seagrass, because changes in water depth can affect several other environmental factors in the waters, namely temperature, light intensity and water hydrodynamics. The intensity of sunlight to a certain depth in the waters is a limiting factor in the growth and production of seagrass. Water clarity is very important for seagrass because it is closely related to the photosynthesis process. Good irradiation will affect the life of seagrass because the photosynthesis process will run well. In addition, this high brightness value is also supported by the relatively calm current speed in these waters.

The water temperature at all locations has an average value of 29.92–32.00 °C. The temperature range does not differ much because the temperature between locations tends to be homogeneous. According to Dahuri (2003), the optimal temperature range for seagrass species is 28–30 °C. The ability of the photosynthesis process will decrease sharply if the water temperature is outside the optimal range.

The salinity value of the waters in all locations ranges from 30.75–32.85‰. This value is included in the range that is suitable for seagrass life. The tolerance range of seagrass to salinity is 10–40‰ (Dahuri et al., 1996). Seagrass growth requires an optimum salinity of 25–35‰ (Supriharyono, 2007).

The average water current speed at Location I was 0.02 m/s and the average current speed value at Location II was 0.02 m/s, a value that was not much different, this happened because the distance between the two locations was close, in contrast to Location III with a current speed value of 0.03 m/s. The current speed is still in a good range for seagrass growth. Dahuri (2001) explained that the speed of water currents affects the productivity of seagrass beds.

The dissolved oxygen content at the research location was still in the normal range and supported the growth of seagrass where at Location I the average value was 4.86 ppm, Location II an average of 4.42 ppm and Location III an average of 5.44 ppm. The minimum dissolved oxygen (DO)

Table 1. Environmental parameters at the research location

Location	Transect	Temp (°C)	Salinity (‰)	Current speed (m/s)	Dissolved oxygen (ppm)	Nitrate (mgL^{-1})	Phosphate (mgL^{-1})	pH
I	I	32.01	31.25	0.02	4.85	1.8584	0.0000	7.56
	II	31.86	32.4	0.02	4.86	1.8526	0.0031	7.26
	III	31.98	32.25	0.02	4.86	2.0670	0.0000	6.25
	Average	31.95	31.97	0.02	4.86	1.9260	0.0010	7.02
II	I	31.86	32.85	0.02	3.55	2.1029	0.0062	6.13
	II	30.03	31.82	0.02	4.85	2.1565	0.0060	6.39
	III	29.92	32.74	0.02	4.85	2.3909	0.0061	6.45
	Average	30.60	32.47	0.02	4.42	2.2168	0.0061	6.32
III	I	30.01	30.75	0.03	5.44	2.0010	0.0000	6.33
	II	30.00	31.82	0.03	5.43	2.1512	0.0000	6.01
	III	30.06	32.74	0.03	5.44	2.2035	0.0016	6.76
	Average	30.02	31.77	0.03	5.44	2.1186	0.0005	6.37

content is 2 ppm under normal conditions and is not contaminated by toxic compounds.

Nitrate is the main form of nitrogen in natural waters and is the main nutrient for seagrass growth. The nitrate value at Location I was an average of 1.9260 mgL^{-1}, Location II an average of 2.2168 mgL^{-1} and Location III an average of 2.1186 mgL^{-1}, while the phosphate (PO^4) content at Location I was an average of 0.00103 mg/L, Location II an average of 0.00610 mgL^{-1} and Location III an average of 0.0053 mgL^{-1}.

The main source of mercury metal entry into the waters of the Talawaan Bajo Estuary is the gold ore mining activities carried out by the surrounding community, in addition, the direct disposal of mercury waste into water bodies greatly affects the condition of water quality, especially in water and sediment. Data on mercury content in the waters of the Talawaan Bajo Estuary are presented in Table 2.

Based on the table data above, the results of the mercury content in water range from 0.025–0.045 mg/L. Based on Government Regulation (PP) number 82 of 2001, the concentration of mercury in water is < 0.001 ppm. This is also supported by the decision of the Minister of Health of the Republic of Indonesia no. 907/menkes/sk/vii/2002 which requires that the permitted mercury content is 0.001 mg/l. By referring to the quality standards, it can be concluded that the waters of the Talawaan Bajo Estuary are polluted. This is because the mercury content in water and sediment has exceeded the specified standard.

Based on the table data above, the results of the mercury content in sediment obtained values ranging from 1.248–2.975 mg/L. The heavy metal mercury is easily soluble and changes stability from carbonate to hydroxide which forms particle bonds in the water, then settles to form mud. The reason why the heavy metal mercury is not detected on the surface of waters is because mercury has the property of returning the metal it contains to the water, so that sediment becomes a potential source of pollution on a certain time scale (Yusuf, et al., 2013).

Furthermore, to determine the levels of heavy metal Hg in seagrass and periphyton samples, and to determine the extent to which heavy metals accumulate in periphyton samples of *Stigeoclonium* sp., Hg concentration treatment was carried out on the periphyton and then the cells were visualized using TEM.

Hg content (ppm) in *Cymodocea rotundata* and *Stigeoclonium* sp.

The results of the analysis of Hg content in *Cymodocea rotundata* can be seen in Table 3 below. Based on Table 3, the Hg levels (ppm) in *Cymodocea rotundata* at the three observation stations were not significantly different, and based on the results of Duncan's further test, it was seen that the lowest Hg levels were at Station 1 with an average of 3.11 ppm and the highest at Station 3, with an average of 4.75 ppm. From the analysis, it was stated that the differences in observation stations (Stations I, II and III) were not significantly different, meaning that the differences in Hg levels in seagrass at the three observation stations were still relatively the same.

Based on Table 4, the Hg levels (ppm) in *Stigeoclonium* sp. at three observation stations were significantly different, and based on the results of Duncan's further test, it was seen that the lowest

Table 3. Average Hg level (ppm) in *Cymodocea rotundata* in the Talawaan Bajo Estuary

Repetition	Station 1	Station 2	Station 3
1	1.77	4.16	8.39
2	3.83	3.51	4.64
3	3.02	4.23	3.33
4	3.14	4.21	4.64
5	3.88	6.45	3.14
6	3.03	4.77	4.37
Average	3.11^{a}	4.56^{a}	4.75^{a}

Note: Same superscript in the same row indicates no significant difference ($P < 0.05$).

Table 2. Mercury (Hg) content in the Talawaan Bajo Estuary

Parameter	Station 1			Station 2			Station 3		
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3
Water	0.025	0.027	0.037	0.043	0.036	0.035	0.045	0.038	0.040
Sediment	1.248	1.376	1.576	2.746	2.875	2.785	2.975	2.763	2.775

Table 4. Hg levels (ppm) in *Stigeoclonium* sp. in *Cymodocea rotundata* seagrass leaves

Ulangan	Stasiun 1	Stasiun 2	Stasiun 3
1	5.94	28.99	39.55
2	5.56	23.05	38.60
3	7.04	15.90	17.96
4	5.54	15.05	20.22
5	12.61	19.81	19.43
6	11.02	17.35	9.26
Rata-rata	7.95^{a}	20.02^{b}	24.17^{b}

Note: different superscripts in the same row indicate significant differences ($P < 0.05$).

Hg levels were at Station 1 with an average of 7.95 ppm and the highest at Station 3, with an average of 24.17 ppm. From the analysis, it was stated that the differences in observation stations (Stations I, II and III) were significantly different, meaning that the differences in Hg levels in *Stigeoclonium* sp at the three observation stations were different.

Accumulation of Hg content in *Stigeoclonium* sp.

Testing of Hg metal levels in *Stigeoclonium* sp. is done by carrying out 4 different treatments using Hg concentrations of 10 ppm, 20 ppm, 30 ppm and 40 ppm to determine how much mercury metal is absorbed in *Stigeoclonium* sp. Based on Figure 1 Hg levels (ppm) of *Stigeoclonium* sp. and water, it can be seen that the lowest Hg levels of *Stigeoclonium* sp. are at a concentration of 10 ppm, namely 8.251 ppm and the highest at a concentration of 40 ppm, namely 31.217 ppm, and for the lowest Hg levels of water are also at a concentration of 10 ppm, namely 1.749 ppm and the highest at a concentration of 40 ppm, namely 8.783 ppm. Based on the results of the one-way ANOVA test, it shows that there is a significant difference in the provision of Hg concentrations in *Stigeoclonium* sp. and its water media.

The treatment shows that the higher the Hg levels given, the higher the value of the Hg level measurement results. According to Li Jie, 2011. Based on this, it can be stated that bioconcentration occurs, namely an increase in the concentration of Hg metal ions in *Stigeoclonium* sp., the value of which is higher than the concentration of Hg metal ions in the water treatment medium. If exposure to toxic materials continues, cells will experience bioaccumulation.

Some organic compounds in the algae body, including chlorophyll, are able to bind heavy metals to form complex compounds through groups that are reactive to heavy metals such as sulfhydryl and amine. The complex bonds cause heavy metals to become more stable and accumulate in algae cells.

According to Yulianto, (2006) the Hg metal content in algae plants is highly dependent on the ability of plants to accumulate waste in the waters of the Talawaan Bajo estuary. The morphological and physiological conditions of these plants are factors that can affect metal absorption. The high concentration of metal absorbed by plants in sea waters will usually decrease in concentration

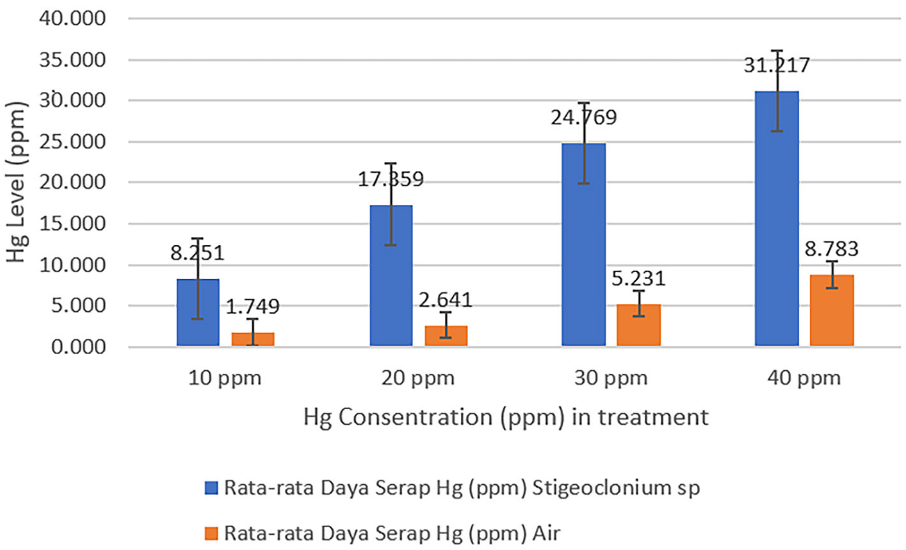

Figure 1. Hg (ppm) in treatment

again because the plants will excrete it again through the filtration process carried by the wave currents so that it can reduce the metal levels contained in the algae.

The physiological response that occurs when plants experience metal stress is the formation of stress proteins (phytochelatins) due to the presence of metal ions that trigger this reaction (Salt DE., 2000). Another response is a change in enzymatic activity. The enzymes involved are reported to use S-adenosylmethionine or vitamin B12 derivatives as metal donors, and in addition to mercury, other metals such as tin, thallium, and metalloids, arsenic, selenium, tellurium, and methylated sulfur. Even reactive metals, gold and platinum are reported as substrates for this fraction.

Stigeoclonium sp. can absorb heavy metals originating from waste disposal in the aquatic environment. The absorption of heavy metal ions found in water is mostly in the form of ions. These heavy metals can cause damage to marine biota if these marine biota continuously accumulate these heavy metals, if the levels of mercury exceed the threshold, it will inhibit the growth of algae. Hg metal is a non-essential metal whose presence in the body of living things can be said to be undesirable, the presence of Hg metal in the body often replaces essential metals in enzyme activity and inhibits enzyme activity (Palar, 2004).

Bioconcentration factor (BCF) is a coefficient to group the efficiency of accumulation of toxic elements in biota and its medium. The BCF value in the treatment shows that *stigeoclonium* at a concentration of 10 ppm is 4.718 times greater in accumulating Hg metal in water, a concentration of 20 ppm is 6.573 times greater in accumulating Hg metal in water, a concentration of 30 ppm is 4.735 times greater in accumulating Hg metal in water and a concentration of 40 ppm is 3.554 times greater in accumulating Hg metal in water. *Stigeoclonium* sp. is an accumulator of Hg metal because the BCF value is > 1 (Janssen, 1997). Thus, *Stigeoclonium* sp is suitable for use as a biomonitoring agent for Hg metal in estuary waters.

Table 5. BCF (o-w) on treatment

Hg concentration	(o – w)
10	4.718
20	6.573
30	4.735
40	3.554

Visualization of mercury in the cell structure of periphyton algae *Stigeoclonium* sp.

The results of histological analysis of *Stigeoclonium* sp. can be seen in the visualization of cell structure using TEM as shown in Figure 2. In Figure 2a, the Hg concentration condition is 10 ppm, the cell structure is slightly damaged, the chloroplasts are still good, the cell walls and cell membranes have been damaged. In Figure 2b, the cell structure is damaged at an Hg concentration of 40 ppm, the chloroplasts and other cell organelles have been lysed and the irregular cell membrane is left behind.

According to Ochiai (1987), the metal ions Hg, Pb and Sn can dissolve in fat and can penetrate the cell membrane wall, so that eventually these metal ions will accumulate in cells and other organs. The accumulation of these metal ions will disrupt enzyme activity and metabolism in cells, so that cell development is inhibited, cells become lysed and die. The results of Gosling's research (1992) stated that heavy metal bioaccumulation can occur in the vacuole system of lysosomal organelles where metals are captured by granules so that metals accumulate and these organelles will cause degeneration.

According to Viarengo (1989) that heavy metal pollution can cause instability of lysosomal organelle membranes in cells. In addition, it also affects the oxidation process, enzyme activity and the balance of Ca ions in cells. As a follow-up to the toxic heavy metal bioaccumulation process, it will undergo biotransformation in cells, causing gene mutations. Sensitive changes occur during cell division at the metaphase stage where changes in chromosome structure will occur due to changes in temperature and environmental chemistry. According to Dixon (1982) it is further explained that prolonged metal pollution can cause changes in the structure of genes in chromosomes and even cause chromosome abrasion, this condition has been proven in blue mussels (M. edulis).

According to Darmono (2001) stated that both heavy metals Hg are metals that are reactive to cells. If the cell binds the wrong metal (non-essential) then it will cause the catalyst dysfunction of the cell itself. Changes that occur in the cell membrane reflect the disruption of ion and volume regulation caused by ATP loss (Robbins and Kumar, 1995). Rupture of the cell membrane causes excess calcium to enter the cell and is followed by mitochondrial swelling due to ion shifts

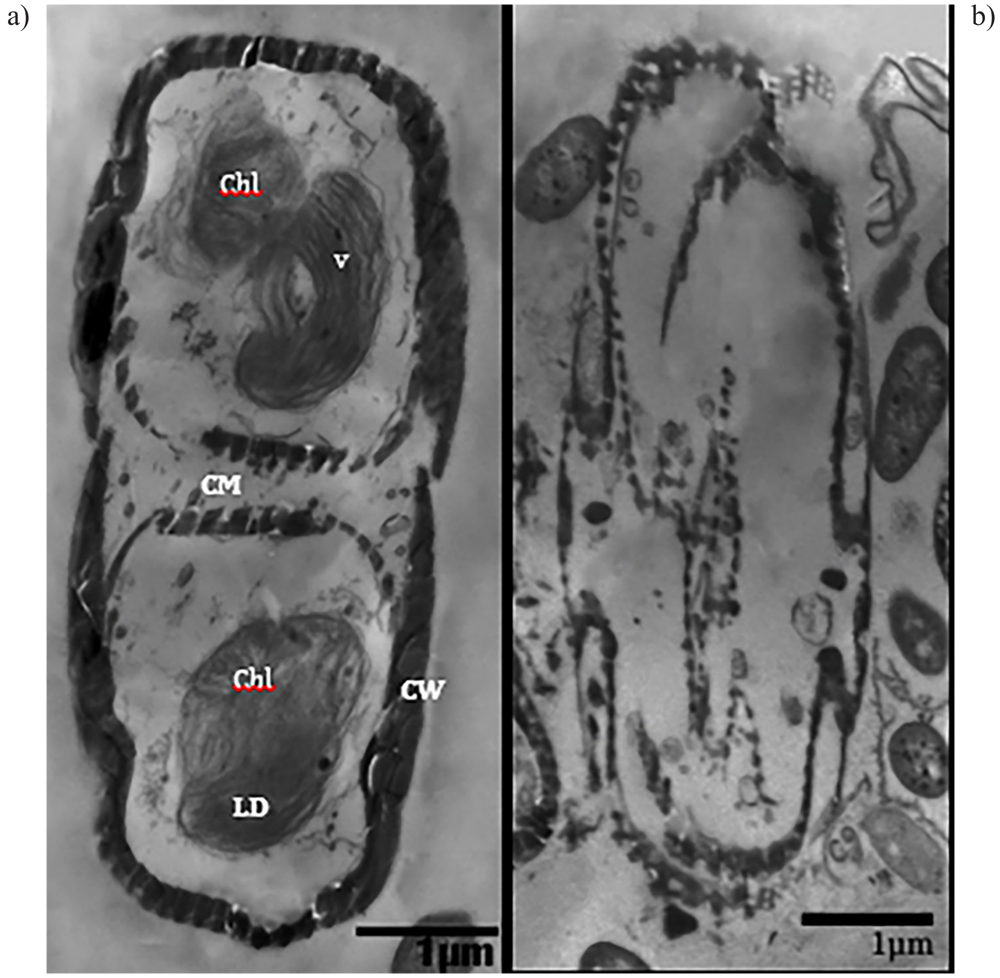

Figure 2. Visualization of *Stigeoclonium* sp cells at a concentration of 10 ppm (a), and 40 ppm (b) using type: TEM JEOL 1010, 80.0 KV Magnification 8000x TEM and Histology Laboratory Eijkman Institute. CW – cell wall; CM – cell membrane; Chl – chloroplast; LD – lipid droplet; V – Vacuola

that occur in the interior of the cell. Followed by widening. Endoplasmic reticulum (ER) followed by ribosome release and polysome rupture accompanied by reduced protein synthesis which continues to progressive fragmentation of the ER and the formation of myelin images.

Changes in lysosomes occur last, torn and disappeared lysosomes are structures found as a form of dead cells. The nucleus of dead cells usually shrinks, the boundaries are irregular and dark in color. The process is called pyknosis and the nucleus is called pyknotic. Furthermore, the nucleus can be destroyed while leaving fragments of chromatin scattered in the cell, the process is called karyorrhexis. Finally, in some circumstances, the nucleus of dead cells loses its ability to be colored and disappears, the process is called karyolysis (Price and Wilson, 1995). The energy supply needed to maintain the function and structure of the ER is reduced and protein synthesis is also reduced. Failure to bind energy due to disruption of mitochondria will cause cells to lose the power to release triglycerides, resulting in fat accumulation known as fatty degeneration. Changes in cells due to the entry of toxic substances can occur quickly and reversibly, but if the situation continues it will become irreversible so that there will be tears in the cell membrane and organelle membrane resulting in cytolysis (Oktavianti, 2004). The results of research by Bell A and Scudder (2005), stated that the accumulation of heavy metal Hg causes cell division of periphyton algae.

As one of the pollutant groups, in general the negative impact of Hg2+ in the metabolic process is to stimulate the process of fat peroxidation through the oxidation of unsaturated long-chain fatty acids (Geret et al., 2002). Fat peroxidation and the resulting damage are modulated by the antioxidant system (superoxide dismutase, catalase, glutathione peroxidase, glutathione) and metallothionein (MT). Metallothionein plays an important role in metal metabolism through detoxification mechanisms. Another function of metallothionein is to protect cells not only as antiradicals but also to behave towards the binding and release of metals. Mercury inhibits enzyme activity and causes cells to be damaged (Blackmore et al., 2004). Organic mercury has high activity against lipids which causes this pollutant to move along the cell membrane and be involved in cell metabolism. Methyl mercury affects the cell division process and causes the results of cell division to receive an unequal number of chromosomes.

BCF value

The results of the calculation of the BCF (o-w) and BCF (o-s) values at each station are shown in Table 6. Based on the calculation results of BCF (o-w) seagrass *Cymodocea rotundata*, namely the comparison between the concentration of heavy metals absorbed by organisms with the concentration of heavy metals in water, the BCF value at station I was obtained, namely 104.90 times greater accumulation of Hg metal in water, Station II 119.92 times greater accumulation of Hg metal in water and station III 115.90 times greater accumulation of Hg metal in water. While the calculation results (BCF o-s) seagrass *Cymodocea rotundata*, namely the comparison between the concentration of heavy metals absorbed by organisms with the concentration of heavy metals in sediment, the BCF value at station I was obtained, namely 2.223 times greater accumulation of Hg metal in sediment, station II 1.626 times greater accumulation of Pb, Hg metal in sediment and Station III 1.675 times greater accumulation of Hg metal in sediment.

The BCF(o-w) values obtained at each station indicate that the seagrass *Cymodocea rotundata* has the ability to accumulate Hg metal in water but is still at a moderate accumulative level, while the (BCF o-s) values obtained at each station indicate that *Cymodocea rotundata* has less ability or has low accumulative levels in accumulating metal in sediment.

Based on the calculation results of BCF (o-w) *Stigeoclonium* sp., namely the comparison between the concentration of heavy metals absorbed by organisms with the concentration of heavy metals in water, the BCF value at station I was obtained, namely. 267.94 times greater accumulation of Hg metal in water, Station II 526.95 times greater accumulation of Hg metal in water and station III 589.51 times greater accumulation of Hg metal in water. Meanwhile, the calculation results (BCF p-l), namely the comparison between the concentration of heavy metals absorbed by *Stigeoclonium* sp. with the concentration of heavy metals in *Cymodocea rotundata*, obtained the BCF value at station I *Stigeoclonium* sp., which was 2.554 times greater in accumulating Hg metal in *Cymodocea rotundata*, station II *Stigeoclonium* sp 4.394 times greater in accumulating Hg metal in *Cymodocea rotundata* and station III *Stigeoclonium* sp 5.086 times greater in accumulating Hg metal in *Cymodocea rotundata*.

The BCF (o-w) value obtained at each station shows that *Stigeoclonium* sp. has the ability to accumulate Hg metal in water but is still in moderate accumulative properties, while the (BCF p-l) value obtained at each station shows that *Stigeoclonium* sp has the ability or has high accumulative properties in accumulating metals in *Cymodocea rotundata*, this occurs because *Stigeoclonium* sp is an organism (planktonic) that obtains its food in the water column, so there is not much heavy metal in the sediment that accumulates in the periphyton body.

Janssen et al. (1997) stated that, if the BCF value > 1 from the concentration in the water column means that the organism has the ability to accumulate metal in the body, conversely BCF ≤ 1 from the concentration in the water means that the organism has less ability to accumulate metal in its body. Ghosh and Singh (2005) explained that there are three categories of BCF values as follows:

Table 6. BCF value of seagrass *Cymodocea rotundata*

Station	BCF (o – w) value	BCF (o – s) value
I	104.90	2.223
II	119.92	1.626
III	115.90	1.675

Table 7. BCF value of *Stigeoclonium* sp.

Station	BCF (o – w) value	BCF (p – l) value
I	267.94	2.554
II	526.95	4.394
III	589.51	5.086

1) BCF values greater than 1000 are categorized as high accumulative properties;
2) BCF values of 100 to 1000 are categorized as moderate accumulative properties;
3) BCF values less than 100 are categorized as low accumulative properties.

Based on the BCF category, seagrass *Cymodocea rotundata* and algae periphyton *Stigeoclonium* sp. have the ability to accumulate heavy metal Hg with moderate accumulation properties. That means this organism is a bioindicator of heavy metal Hg in waters. *Stigeoclonium* sp. is often used as an indicator of aquatic environments enriched or polluted by organic compounds and is also reported to be tolerant to heavy metal pollution (Bellinger, 2015). In his research, Fukuyo (2000) stated that *Stigeoclonium* sp. is included in the indicator of heavy pollution.

CONCLUSIONS

Based on the analysis results, it can be seen that the environmental conditions of the Talawaan Bajo estuary are contaminated with mercury because the Hg content accumulated in seagrass and periphyton exceeds the quality standards for aquatic biota. Hg contamination in aquatic ecosystems affects the life of biota in the environment, especially damage to tissue structures. Periphyton *Stigeoclonium* sp is a bioindicator of heavy metal Hg in the waters of the Talawaan Bajo River estuary, because it is able to adapt to the environmental conditions of waters that have been exposed to heavy metal Hg. The North Minahasa Regency Government together with the Tatelu gold miners and the community around the Talawaan Bajo River Basin Area should create/issue regulations on environmental management of river basins, coasts and seas.

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