Eco. Env. & Cons. 27 (3) : 2021; pp. (1265-1277)
Copyright@ EM International
ISSN 0971–765X

Relationship between Lead (Pb) in Sediment, Seaweed and Brackish Water Ponds in Tegal City

[1,2]Nurjanah, [3]Ambariyanto, [3]Supriharyono and [3]Bambang Yulianto

[1]Doctoral Program in Water Resources Management, Universitas Diponegoro, Semarang, Indonesia
[2]Faculty of Fisheries and Marine Science, Universitas Pancasakti Tegal, Jawa Tengah, Indonesia
[3]Faculty of Fisheries and Marine Science, Universitas Diponegoro, Semarang, Indonesia

(Received 30 November, 2020; Accepted 31 December, 2020)

ABSTRACT

Pb pollution caused by industrial and domestic waste is harmful to coastal areas, including ponds. In the present study, Pb concentration was measured from eight seaweed ponds. This study analyzed the relationship between Pb and water quality parameters in seaweed (*Gracilaria verucosa*) ponds. Pb concentration in the pond water ranged from undetected to 0.025 mg l-1, Pb concentration in sediment ranged from 6,377 to 23,699 mg l-1, and that in seaweed ranged from Pb 0,028 to 3,240 mg l-1. Regression equation for relationship between Pb in water and Pb in sediment was Z = Pb Z = 13,702-207X, R = 0,408, R2 = 0,167, The equation for relation between Pb in water and Pb in seaweed was Y = 0,006 + 44,833X, R = 0,346, R2 = 0,120, and the relation between Pb in sediment and Pb in sediment and Pb in seaweed was Y = 1,759-0,117Z, R = 0,453, R2 = 0,211. Pb concentration of the ponds water was below the quality standard determined by the Indonesian Ministry of Environment. Following PCA analysis, it was concluded that the Pb concentration in seaweed ponds was affected by pH (66.44%), salinity (23.34%), and nitrite (10.22%).

Key words : *Relationship, Pb, Gracilaria verrucosa, Water quaity, Pond*

Introduction

Gracilaria verrucosa is a potential commodity due to its easy production technique, relatively low risk of harvest failure, and high productivity, and high selling price. Seaweed farming can create significant economic multiplier effects since it absorbs many employments (Dahuri, 2011). Seaweed is a source of food that be directly consumed, or be used as animal feed, fertilizer, biogas, beauty, and pharmacy products (Valderrama *et al.*, 2013).

Pb is one of the toxic and hazardous heavy metals (Darmono, 2006). Heavy metals that contaminate pond water and sediment may be accumulated in biota and affect its growth starting at the organism level until community, and even ecosystem level. Responses that occur in an aquatic ecosystem include bioconcentration, bioaccumulation, and biomagnification (Puspitasari, 2007). Heavy metal pollution that ecological damages the aquatic ecosystem by heavy metal pollution that ecologically damages the aquatic ecosystem is determined by pollutant's level and continuity, bioaccumulation, and toxicity (Ambariyanto, 2011).

Seaweed can act as biofilter (Komarawidjaya, 2005), which efficiently absorb nitrogen (Matos *et al.*, 2006), ammonia (Shimmoda *et al.*, 2006), phosphate (Komarawidjaya, 2008), and as biosorbent (Ata *et al.*, 2012; Raya and Romlah, 2012) and bioremediation agents (Ihsan *et al.*, 2015). Pb content in water can be minimized by using seaweed *G. verrucosa* (Handhani *et al.,* 2017; Yulianto *et al.,* 2018). Previous studies showed that *G.verrucosa* can be used to improve water quality. Therefore, the present study aimed to find out the relationship between Pb pollution and pond's environmental parameter using regression analysis and PCA.

Materials and Methods

The present study was conducted from April to May 2015 in eight *G.verrucosa* ponds in Muarareja, Tegal city, Indonesia (Figure 1).

G.verrucosa ponds were located in Kemiri river that disembogues to Java sea. Kemiri river is a river located in the Tegal city downstream, which receives wastes from the upstream and its surroundings due to industrial, agricultural, farming, and residential activities.

Sample collection.

The sample of the study was water, sediment, and seaweed *G.verrucosa*. This exploratory study employed purposive sampling technique. In situ measurement was carried out to measure the water temperature, pH, and Salinity. Meanwhile, ex-situ measurement was conducted in the Faculty of Fisheries and Marine Science Laboratory of Pancasakti University, Tegal, to measure the nitrate. Pb concentration in water, sediment, and seaweed was measured

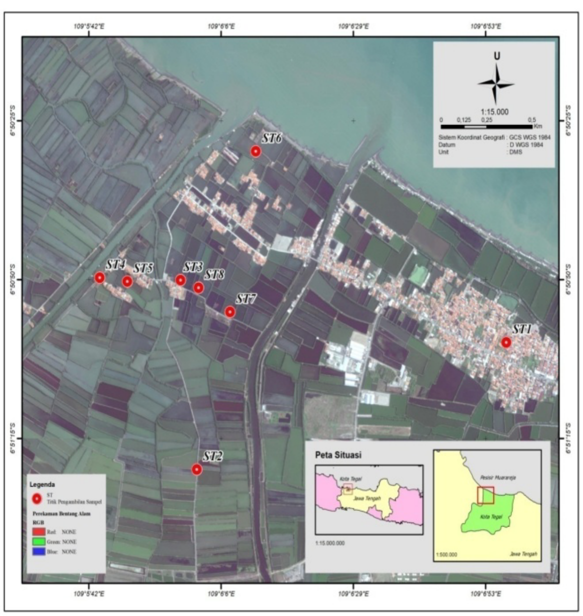


Fig. 1. Location map

in Land Resource Laboratory of Faculty of Agriculture, Jenderal Sudirman University, Purwokerto, Indonesia. Pb was analyzed using Atomic Absorption Spectrophotometer (AAS). The water, sediment, and seaweed samples were prepared following Indonesian National Standard 6989.8: 2009. The Pb concentration in water, sediment, and seaweed was analyzed based on Hutagalung's (1997) procedure.

The water sample preparation was done by taking and shaking 100 ml water sample, and then put into the chemical glass, and was added by 5 ml of nitrate acid (HNO_3). The water sample was heated in an electric heater. After that, 50 ml of distilled water was added. The sample was then put in a 100 ml volumetric flask through a filter paper. The sample was stored in a plastic bottle and was ready to be analyzed using AAS.

The sediment sample preparation was done by putting the sample into a Polyethylene bottle that had been washed/soaked in HNO_3 (6 N) and rinsed with distilled water. After that, the sample was put into a container and dried up in an oven at the temperature of 105 °C for 24 hours. After shaken with distilled water, the sample was dried up at a temperature of 100 °C for 24 hours and then pounded. 5 gram of dry sediment sample was put into a container and was stored at room temperature for approximately 4 hours. The crushing was done at 90 °C for 8 hours. Pb in sediment was determined using AAS.

Seaweed *G. verrucosa* sample preparation was done by separating samples from inorganic materials using the following steps: the seaweed was taken and washed using running water and washed again using aquadest. The sample was put in petri dish and put into an oven and dried up at 105 °C. 10 grams of the sample was put into a porcelain glass, then 10 ml of HNO_3 , $H4SO_4$ were added. After that, the sample was cooled down and dissolved in distilled water and filtered using a 50 ml filter paper. The sample was then stored in glass bottles and ready to be analyzed using AAS.

Statistical Analysis

In this study, SPSS version 21.0 was used to analyze the data. ANOVA test was employed to find out the average value of Pb concentration in water, sediment, and *G.verrucosa* in the research location. Duncan test was also carried out to find out the difference in the average accumulation of Pb in water, sediment, and *G.verrucosa*. Water quality parameter was analyzed descriptively. The regression analysis was done to find out the relationship between water quality parameter and Pb in water, sediment, and seaweed. Principal Component Analysis (PCA) was used to find out recommended environmental management strategies for Tegal City Government and stakeholders.

The data on Pb concentration in water, sediment, and seaweed were analyzed descriptively by comparing the laboratory analysis result to the quality standard. In determining Pb in water, Pb in seaweed, and Pb in sediment, Ministry of Environment Regulation no. 51 of 2004, SNI 7387-2009, and quality standard from ANZECC/ARMCANZ (2000), CCME (2002), SEPA (2000), and NOAA (1999) were used, respectively. Data on the parameter of water quality were descriptively analyzed based on the quality standard issued by the Ministry of Environment no. 115 of 2003 and no. 51 of 2004.

Results and Discussion

Pb concentration in seaweed ponds

Table 1 displays the measurement result of Pb concentration in water, sediment, and seaweed in eight seaweed ponds.

Pb Concentration in Water

In this study, Pb concentration in water ranged from 0 to 0,025 mg l^{-1} in sample 1 and 0,003 to 0,009 mg l^{-1} in sample 2. The result of the study showed that Pb concentration in water in sample 1 was relatively lower than that of sample 2. Pb in water during this study was still below the quality standard determined by the Minister of Environment regulation no. 115 of 2003, i.e., 0.03 mg l^{-1}. The graph of Pb in water in the course of the study is shown in Fig. 2.

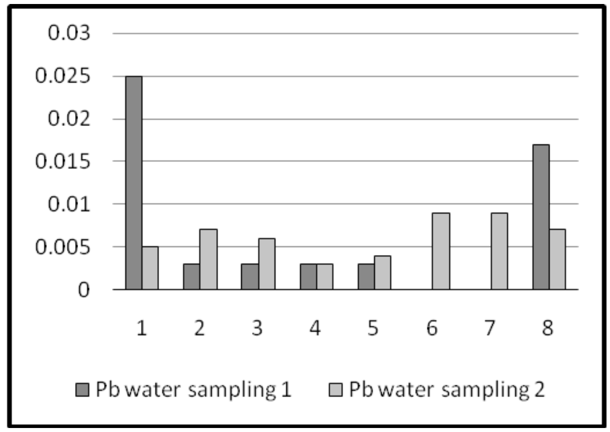


Fig. 2. Pb in water (mg L^{-1}) in eight stations during the study.

Pb concentration in the Sediment

Pb concentration in the sediment when the study was conducted ranged from 12.838 to 23.699 mg l^{-1} in sample 1 and from 6.377 to 9.858 mg l^{-1} in sample 2. The result of the study showed that Pb concentration in sediment in sample 1 was relatively lower than that of sample 2. Pb in sediment was below the quality standard from ANZECC / ARMCANZ (50 mg l^{-1}), CCME (30,2 mg l^{-1}), SEPA ($\leq$ 50 mg l^{-1}), dan NOAA (46,7 mg l^{-1}). The graph of Pb in Sediment in the present study is shown in Figure 3.

Pb concentration in seaweed

Pb in *G.verrucosa* in sample1 ranged from 0,028-0,326 mg l^{-1} while that in sample 2 ranged from 0,036-3,240 mg l^{-1}. The result of the study showed that Pb concentration in sample 1 was relatively

Table 1. Pb concentration (mg·L^{-1}) measurement result of eight seaweed ponds.

Station	Pb in pond water		Pb in pond sediment		Pb in seaweed	
	1	2	1	2	1	2
1	0,025	0,005	16,688	7,680	0,028	0,036
2	0,003	0,007	19,204	8,020	0,313	0,037
3	0,003	0,006	1,375	8,352	0,214	0,079
4	0,003	0,003	13,957	8,165	0,326	0,038
5	0,003	0,004	23,699	9,858	0,209	0,038
6	-	0,009	17,257	6,377	0,305	0,039
7	-	0,009	13,974	7,678	0,219	0,042
8	0,017	0,007	12,838	6,469	0,212	3,240
Mean	0,009	0,006	16,421	7,825	0,228	0,444
Standard Deviation	0,010	0,002	3,655	1,105	0,095	1,130

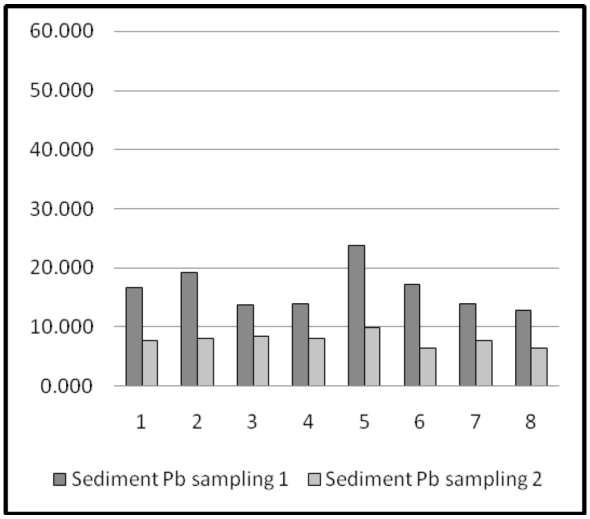


Fig. 3. Pb in Sediment (mg L^{-1}) in eight stations in the present the study

lower than that of sample 2. Pb in seaweed when the study was conducted was below the quality standard issued of Indonesian National Standard no. 7387-2009 (i.e. 0.5 mg l^{-1}.) Pb in seaweed is shown in Figure 4.

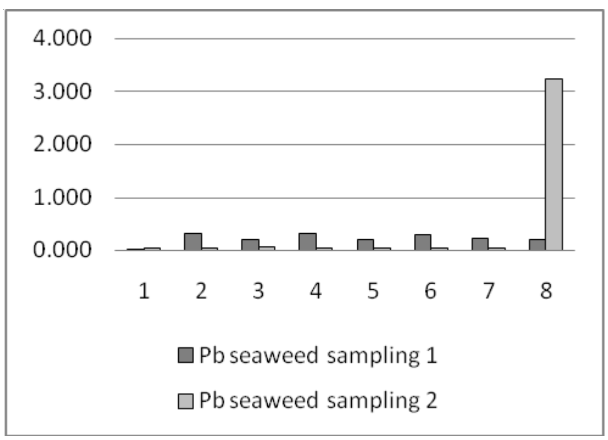


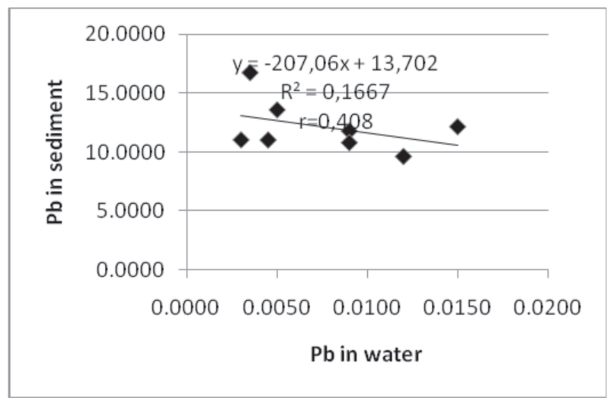
Fig. 4. Pb in seaweed *G.verrucosa* (mg l^{-1}) in eight stations

Water Quality Parameters

Pb concentration is influenced by external and internal factors. The external factor includes the water quality parameters. Water quality affects the growth and life of cultivant (Sri Puryono *et al.*, 2019). Water temperature serves as controlling factor, dissolved oxygen and nitrate serves as limiting factor, salinity serves as the masking factor,and pH serves as the directive factor of biochemical reaction in water (Gerking, 1978). The measurement result of the water quality parameter during the study is presented in Table 2.

Correlation between Pb in Water and Pb in Sediment

Based on the regression analysis, the regression equation was Z = 13,702-207,057 X withR 0.408 and R2 of 0.167. Pb concentration in sediment was found to have a negative correlation with Pb concentration in water. In other words, the increase in Pb concentration in water will lead to lower Pb concentration in sediment. The correlation value of 0.408 indicated a moderate relationship between Pb concentration in water and Pb concentration in sediment, while the coefficient of determination of 0.165 indicated that Pb concentration in sediment was accounted for by Pb in pond water by 16.7%.



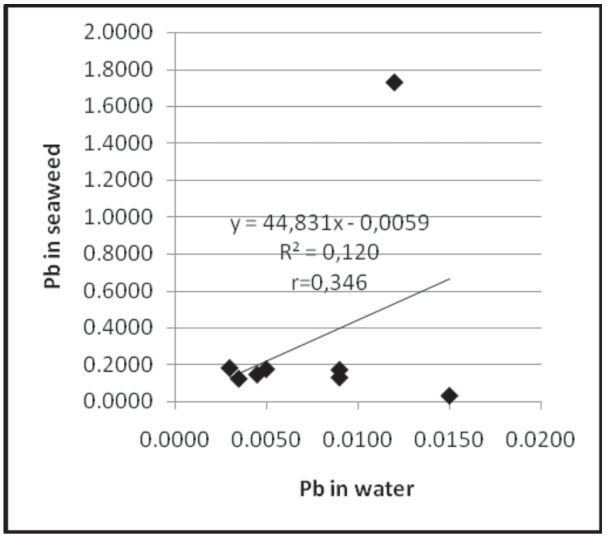
Graph 4. Correlation between Pb in Water and Pb in Sediment

Correlation between Pb in Water and Pb in *G.verrucosa*

The regression equation was Y = -0,006+44,833X with R=0.346 and R^2 = 0,120. Pb concentration in seaweed was found to be positively associated with Pb concentration in water. In general, higher Pb concentration in water leads to higher Pb concentration in seaweed.

Correlation between Pb in Sediment and Pb in *G.verrucosa*

The regression equation was Y = 1,759-0,117Z with R=0.459 and R2 = 0,211. Pb concentration in sediment was found to have a negative correlation with Pb concentration in seaweed. In other words, higher Pb in sediment results in lower Pb concentration in seaweed. A correlation value of 0.459 indicates a



Graph 5. Correlation between Pb in water and Pb in seaweed

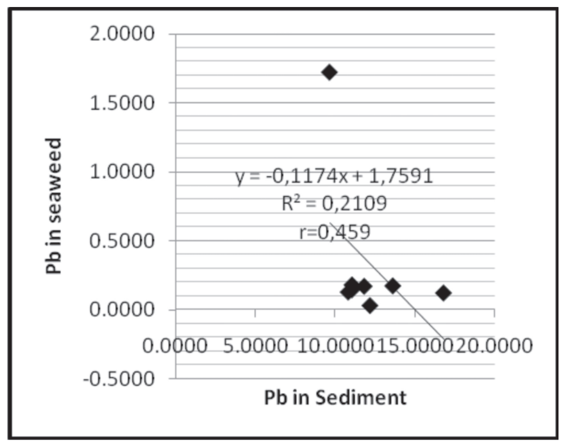
moderate relationship between Pb concentration in sediment and Pb concentration seaweed. The coefficient of determination of 0.211 indicates that Pb concentration in sediment accounts for Pb concentration in sediment by 21.1%.

Water Quality Parameters

Table 2 displays the measured water quality parameter in this study.

The water temperature tolerance, according to Asni (2015) is between 24-35 °C (Asni, 2005). In the present study, the temperature ranged from 25 to 34 °C (Asni, 2015). It means that the temperature is still within the tolerance level of seaweed. When the study was conducted, the depth of the pond was between 55-130 cm. The optimum depth for seaweed growth is 0.3 to 0.8 m (Susilowati *et al.*, 2012).

The brightness level of the pond was between 35-80 cm. According to Sunarto (2009), The water brightness should be between 0.3-0.5 cm. Accordingly, the brightness of water in this study is still within the tolerance level of *G.verrucosa* growth. In situ measurement on pH found a value ranging from 7.2 to 8.2 pH value in *G.verrucosa* ponds measured in this study is still within the Threshold Value Level issued by the Ministry of Environment (2004). The soil pH value was 6.8-7, which is within the threshold limit value, i.e., 6-8.5 (Ministry of En-



Graph 6. Relationship between Pb in sediment and Pb in seaweed.

Table 2. Water Quality Parameter during the study

No.	Category	Range	Average	Standard deviation	Quality standard
1.	Temperature	25-34	30.375	2,3058	25-34
2.	Depth	55-130	86.875	18,8534	>50
3.	Brightness	35-80	56.8125	13,5017	30-40
4.	Water pH	7.2-8.2	7.6275	0,2896	7-8/5
5.	Soil pH	6.8-7.0	6.9125	0,0619	6.5-8.5
6.	Salinity	12-30	21.25-2297	5,3229	15-34
7.	Oxygen	4.68-13.90	8.21375	3,2297	>5
8.	Nitrate	0.001-1.85	0.38319	0,6591	10
9.	Nitrite	0.0001-0.28	0.02247	0,0698	0.06
10.	Ammonia	0.001-0.38	0.15181	0,1778	0.3
11.	Phosphate	0.001-2.24	0.77906	0,8562	0.2
12.	BOD	2.3-12.77	7.29	2,9387	20
13.	N Total	0.40-23.14	11.7713	10,6268	30
14.	TSS	0.031-0.117	0.06413	0,0270	20
15.	TOM	1.08-47.57	18.175	20,2126	20-30

vironment, 2003).

In this study, the salinity of ponds was 12-30 promil. *Gracillaria sp.'s* adaptation ability is optimum in 17-40 ppt (Komarawidjaya, 2005), while according to the Department of Marine and Fisheries (2011), the salinity for seaweed growth should range from 12 to 30 promil. Dissolved oxygen in *G.verrucosa* ponds in the present study ranged from 4.68-13.89 mg L^{-1} and was within the TLV determined by the Ministry of Environment (2004), i.e., >5 mg/l.

Nitrate concentration in ponds water when the study was conducted ranged from 0.001 to 1.85 mgl^{-1}. According to Soelistiyowati *et al*. (2011), seaweed grows optimally in nitrate content of 0.1 – 0.7 mg L-1 (Soelistiyowati *et al.,* 2011). The maximum limit of nitrate is 10 mg/l (Ovez, 2006). Nitrite concentration in ponds water when the study was conducted ranged from 0.001 to 1.85 mgl^{-1}, while according to Minister of Health Regulation 492/2010, the quality standard is 3 mg/l. The ammonia concentration in ponds was 0.001-0.38 mgL^{-1}, whilethe quality standard is 0.3 mg/l (Ministry of Environment, 2003). Nitrate concentration in ponds water when the study was conducted ranged from 0,001 to 2.24 mgl^{-1}. Good phosphate level for seaweed farming is 0.1–0.2 mgL^{-1} (Soelistiyowati *et al.,* 2014).

The biological oxygen demand (BOD) concentration in ponds was 2.3–12.77 $mgl^{-1,}$ while the quality standard is 20 mg/l (Ministry of Environment, 2004). Total of N concentration in ponds was 0.40-23,14 mgl^{-1}, which is within the quality standard of 30 mg l^{-1} (Ministry of Environment, 1995).

The Total Suspended Solid concentration in ponds was 0.031-0.117 mg l^{-1} and was within the quality standard of 20 mg/l (Ministry of Environment, 2004). The Total Organic Matter concentration in ponds was 0.001–12.77 mg l^{-1} and was within TOM quality standard i.e. 20-30 mg/l (Rakhman, 1999).

PCA Analysis

PCA analysis result showed that Pb concentration in seaweed ponds was affected by pH by 66.44%, salinity by 23.34%, and nitrite by 10.22%. This result can depict overall water quality. It was found that the water pH was a component with the highest variance (i.e., 66.439). Thus, the water quality characteristic was mostly affected by the water pH. The movement of metal in sediment to the groundwater in the coastal area is greatly affected and controlled by water pH and salinity (Simpson *et al.,* 2016). Connectivity of heavy metal in sediment, seawater, and groundwater is caused by the changes in pH and salinity of sediment and water (Suryono, 2016).

Pb concentration in water and Pb in the sediment

Pb concentration in pond water in sample 1 was lower than that of sample 2. This difference is accounted for by the season when the sample was taken, where the water temperature of sample 1 is higher than that of sample 2. Pb concentration in water during this study was still below the quality standard, i.e 0.03 mg l^{-1} stipulated by the Ministry of Environment Regulation no. 115 of 2003.

Pb concentration in pond sediment in sample 1 was lower than that of sample 2. This difference is accounted for by the season when the sample was taken, where the water temperature of sample 1 is higher than that of sample 2. Pb concentration in sediment during this study was still below quality standard according to ANZECC/ARMCANZ (50 mg/l), CCME (30.2 mg/l), SEPA(≤ 50 mg/l), or NOA (46.7 mg/l).

The measurement result showed that Pb concentration in sediment was higher than Pb concentration in water. This was caused by the heavy metal binding property that binds organic materials and sediments in the river bed. Thus the heavy metal concentration in sediment is higher than that in water (Bhosale and Sahu, 1991; Connell and Miller, 2006).

Pb concentration in Sediment and Pb concentration in *G. verrucosa*

Tegal is a densely-populated coastal area with various activities that produce Pb pollutant that harms water environment, including *G. verrucosa* ponds. Heavy metal may be produced by industrial waste, mining waste,domestic waste, and agricultural waste (Burchett, 2002; Amin *et al.,* 2011). Given that heavy metal accumulation depends on location, it is necessary to monitor heavy metal concentration in seaweed cultivated downstream (Kim *et al.,* 2019).

The measurement result showed that Pb concentration in sediment was higher than Pb concentration in seaweed *G.verrucosa.* The regression equation indicated a negative correlation between Pb in sediment and Pb seaweed. In other words, When Pb in pond Sediment decreases, the Pb concentration in seaweed tends to increase, and vice versa. A possible explanation for this phenomenon is that the

Pb in sediment has been absorbed into the thallus.

In the present study, Pb in *G.verrucosa* of sample 1 ranged from 0.028 – 0.326 mg l^{-1}, and that in sample 2 ranged from 0.036 – 3.240 mg l^{-1}. Pb concentration in *G.verrucosa* of sample 1 was lower than that of sample 2. This difference is accounted for by the season when the sample was taken, where the water temperature of sample 1 is higher than that of sample 2. The Pb concentration in seaweed when this study was conducted was below the quality standard determined by the Indonesian National Standard (SNI) no. 7378-2009, i.e., 0.5 mg/kg.

Pb in sediment was also higher than Pb in seaweed. The accumulation of Pb occurs because Pb, along with organic materials contained in seaweed thallus, forms a complex compound that makes Pb stays in the thallus and unexcretable (Lobban and Harrison, 1994). Some indications of excessive heavy metal are the decrease and hindrance in nutrition absorption of plant, hindering the metabolism process (Chino, 1981; Kang dan Sui, 2010; Ihsan *et al.,* 2015).

Correlation between Pb in sediment and Pb in water

The regression equation indicates a negative correlation between Pb in sediment and Pb in water. When Pb in pond water decreases, the Pb concentration in sediment tends to increase, and vice versa. Pb in sediment was found to be higher than Pb in pond water, this possibly occurs because Pb in pond water is adsorbed into the pond sediment. Pb is bioaccumulative, its concentration increases in water and greater when it is in sediment (Sitorus, 2004). Heavy metal can bind organic material and settles in sediment (Connell dan Miller, 2006). According to Purwiyanto (2015), sediment-water interaction is affected by internal and external factors of heavy metal. The internal factor is the heavy metal's adsorption system and the binding with other elements in water (e.g., suspended solid), while the external factor is related to the turbulence in water. Adsorption and binding process causes metal to interact with other elements, thus forming heavier molecule flocculants that allow heavy metal in water to sediment.

Correlation between Pb in water and Pb in *G. verrucosa*

The regression equation indicates a positive correlation between Pb in water and Pb in seaweed. When Pb concentration in pond water decreases, Pb concentration in seaweed also decreases. A possible explanation for this phenomenon is that the Pb in water has been absorbed into thallus. The difference was found in station 1 and station 8. In station 1, low Pb concentration in seaweed is followed by high Pb concentration in the pond water, this may occur possibly because Pb in water had not sedimented into the pond sediment. Meanwhile, in station 8, high Pb concentration was followed by high Pb concentration in the water.

Correlation between Pb in seaweed and Water Quality Parameters

Heavy metal concentration is influenced by external and internal factors. The external factor is the water quality parameter. Seaweed growth is affected by the physical and chemical factors of water, namely stream, salinity, nitrate, and sunlight (Atmadja *et al.,* 2012). Seaweed growth highly depends on its environment (Rohman *et al.,* 2018). Table 2 displays the measured water quality parameters in this study.

Tegal is a densely-populated coastal area with various activities that produce Pb pollutant that harms water environment, including G. verrucosa ponds. Heavy metal may be produced by industrial waste, mining waste, domestic waste, and agricultural waste (Burchett, 2002; Amin *et al.,* 2011). Domestic and industrial waste damage water quality (Siaka, 2016). Given that heavy metal accumulation depends on location, It is necessary to monitor heavy metal concentration in seaweed cultivated downstream (Kim *et al.,* 2019).

The accumulation of heavy metal within an organism depends on the concentration of heavy metal in water or environment, temperature, species condition, and physiological activities (Connel dan Miller, 1995). The water temperature measured in this study was within the quality standard. Water temperature is a physical parameter affecting the chemical reaction and distribution of organisms. Besides, it is a factor that directly affects metabolic rate, growth rate, and survival rate. Water temperature is influenced by substrate composition, turbidity, rainwater, the surface area exposed to sunlight, and water runoff (Perkins, 1974).

When the study was conducted, the depth of the pond was within the quality standard. According to Ma'ruf *et al.,* (2013), Seaweed *Gracilaria sp* exhibits better growth in shallow areas. The depth of pond water is also important since it deals with the sunlight penetration required for the photosynthesis process.

Brightness functions to help the photosynthesis process of seaweed. *G.verrucosa's* growth is correlated with solar radiation (Whyte *et al.,* 1981). The brightness of the pond was still in the tolerance level for *G. verrucosa* growth.

Lack of solar exposure may obstruct the growth of aquatic biota (Hardjojo and Djoksetiyanto, 2005). The measurement result showed that Ph in pond water and groundwater were still within the quality standard. Optimum pH level for *Gracilaria sp* growth ranges from 6.0 to 9.0 (Widiastuti, 2011). Acidity holds important role in metal dissolubility in water (Waldichuk, 1974). An increase in temperature, a decrease in pH, and salinity of water may lead to higher heavy metal accumulation. Increase in pH level may lower heavy metal solubility in water because it changes the stability from carbonate form into hydroxide that creates binding with particles in the water body, thus accumulated in sediment (Palar, 2012).

Based on the measurement, the salinity of the ponds was in the quality standard. Changes in salinity may result in fluctuating biochemical and physiological responses of seaweed. While hyposalinity may cause seaweed not to grow normally, has pale color, and rot (Asni, 2015), Hypersalinity may hinder the seaweed reproduction (Atmadja *et al.,* 2012).

Dissolved Oxygen (DO) in *G.verrucosa* ponds in the present study was still within the Threshold limit value determined by the Indonesian Ministry of Environment. Seaweed can grow optimally in non-polluted water with DO of > 6.5 ppm (Aslan, 2006). Organism uses DO for respiration and are used for organic substance decomposition by a microorganism. Water oxygen is originated from the air through diffusion and photosynthesis processes of phytoplankton and seaweed. It serves as an indicator of water fertility. The level of DO continues to decrease when more organic wastes enter the water. This decrease occurs because oxygen is used by bacterias to decompose organic matters (Simanjuntak, 2012). DO content is negatively correlated with metal concentration in water (Hutagalung, 1991).

The present study found that nitrate concentration in pond water was within the quality standard. The maximum limit of nitrate is 10 mg/l (Ovez, 2006). Nitrate is a limiting factor required for the formation of aquatic biota protoplasm. Nitrate is needed by living organisms and seaweed photosynthesis. High nitrate content comes from the result of metabolism of organism and decomposition process (Koesbiono, 1980). The abundance of organisms in water depends on the nutrient concentration, i.e., nitrate and phosphate (Nybakken, 1992). Seaweed in coastal areas can decrease eutrophication of 75.000 t N and 9,500 t P of nutrient every year, which is equal to 17.8 ha N and 126.7 ha P (Xixiao *et al.,* 2017).

Nitrite concentration in pond water when the study was conducted is still in nitrite quality standard according to Regulation of Minister of Health. Nitrite is one of the nitrogen compounds and the result of oxidation of ammonia. Nitrogen may affect water quality (Aswadi, 2006).

Ammonia concentration in pond water when the study was conducted was still within the quality standard according to Ministry of Environment (2003). The source of ammonia is liquid waste (e.g., domestic, agricultural, and industrial wastes) (Bonnin *et al.,* 2008).

Phosphate concentration in water found in this study was still within the quality standard for cultivation. Phosphate is sourced from sediment and other anthropogenic activities. The stirring process in the water bottom and circulation process in the surface also affect the phosphate content. In general, phosphate content increase along with the water depth. Lower phosphate level is found in the surface layer, while higher phosphate level is found in the deeper layer.

The biological oxygen demand concentration in water was within the quality standard determined by Ministry of Environment (2004). BOD refers to amount of required oxygen to dissolve or to degrade organic compounds with the help of microorganisms (Purwanto, 2005).

N concentration in pond water when the study was conducted was still within the quality standard according to Ministry of Environment (1995). It was found that the highest inorganic material was 14.93% in 15 meters deep. The value of inorganic material in the depth of 0-31 meters ranged from 1.02% to 14.93%. This indicates that two different environments lead to a change in the grain size.

The Total Suspended Solid (TSS) concentration in water was within the quality standard determined by Ministry of Environment (2004). TSS refers to solid materials consisting of organic and inorganic materials suspended in water. High TSS value may lower the photosynthesis activity of sea plants, which is dangerous for aquatic biota (Jiyah *et al.,* 2017). TSS is affected by the particle-size distribution, density, and particle composition (Neukermans *et al.,* 2012).

Total Organic Matter (TOM) concentration in pond water when the study was conducted was in the quality standard. Organic material content is associated with sediment grain size (Wood, 1987). Fine sediment has a higher percentage of organic materials than coarse sediment does. The calm environment allows fine sedimentation and is followed by high organic material accumulation (Maslukah, 2013). Silt grain contains a higher percentage of organic matter than sand grain does. In samples, 1-30 meters, varied and fluctuating organic values of 20-40% were found. Grain size affects organic material content, as shown in the depth of 0-31 meters that have finer grain and higher organic values (Astriandhita *et al.,* 2017). The water condition depicts a change in organic carbon. High organic value originates from land, which is brought by the runoff and from the sea, i.e., sea organism production (Yun *et al.,* 2015).

PCA Analysis

PCA analysis result showed that three components of water quality affect Pb concentration in seaweed ponds, namely pH, salinity, and nitrite. The most dominant water quality parameter to affect Pb concentration is pH.

The movement of metal in sediment to the groundwater in the coastal area is greatly affected and controlled by the water pH level and salinity (Simpson *et al.,* 2016). Connectivity of heavy metal in sediment, seawater, and groundwater is caused by the changes in pH and salinity of sediment and water (Suryono, 2016).

Reeves (1992) argues that a plant that can absorb heavy metal with a minimum concentration of 1000 g/g of biomass is called a hyperaccumulator. Hyperaccumulator plants can tolerate up to 10 to 20 times larger than the maximum tolerated value of normal plant and can produce higher biomass. Yulianto *et al.* (2018) state that almost all plant species experience significant biomass loss if the heavy metal concentrated inside their tissues.

Purnamawati *et al.,* (2015) argue that heavy metal ion that enters plants can bind the protein and polysaccharide. Before the metal ion arrives in cell membrane and cell cytoplasm, it passes the cell wall. Cell wall is the most important part of cell defense mechanism because it serves as the first barrier against toxic heavy metal accumulation. Metal ion that enters the cell's organ will bind to Phytochelatin transported to vacuole to lower the toxic effect on the plant. The absorption and accumulation process of toxic substances within the cell will be broken down and excreted, stored, or metabolized by the organism, depending on the chemical concentration and potential (Heryanti *et al.,* 2009).

The form thallus of seaweed *G.verrucosa* is like cartilage, allowing it to have a better ability to absorb Pb more effectively. Pb gets into macroalgae through several stages, namely adsorption, absorption, metabolism, detoxification, interaction, and toxic effect (Soemirat, 2005).

According to Ariyanti and Intan (2012), Pb absorption in water by *G.verrucosa* occurs through physical adsorption mechanisms due to Van der Waals force. This force occurs between the heavy metal ion and *G. verrucosa* cell wall.

Given that heavy metal accumulation depends on location, It is necessary to monitor heavy metal concentration in seaweed cultivated downstream (Kim *et al.,* 2019). Daily seaweed consumption (4g day^{-1})contributes to the intake of Pb of 0.0003 mg day-1 (Rubio *et al.,* 2017). Heavy metals in water can be originated from natural sources and human activities. Natural sources get into waters from rock erosion, metal particle in the air, and rain. With regard to human activities, waste disposal and transportation may produce heavy metals (Payong and Rusian, 2013).

The movement of metal in sediment to the groundwater in coastal areas is greatly affected and controlled by water pH and salinity (Simpson *et al.,* 2004). Connectivity of heavy metal in sediment, seawater, and groundwater is caused by the changes in ph and salinity of sediment and water (Suryono, 2016). Appelo and Postma (1996) argue that compared to water, sediment contains a higher amount of heavy metal because sediment absorption of metal particles is more dominant, given that metal tends to bind hydroxide and organic matter in sediment.

Pb content in water could be minimized using seaweed *G. verrucosa* as the remediator that can absorb toxic materials. Previous studies showed that seaweed can function as biosorbent Cd (Raya and Ramlah, 2012), Cu heavy metal biosorption by

Gracilaria sp. (Yulianto *et al.,* 2006; Ariyanti dan Intan, 2012; Yulianto *et al*., 2018), Cr heavy metal absorber (VI) (Ata *et al.,* 2012), and Pb heavy metal absorber (Ihsan *et al.,* 2015; Handhani *et al.,* 2017). *Gracilaria* farming can gives more ecological benefit for the environment (Kim *et al.,* 201). The result of the study showed that seaweed *G. verrucosa* has ability to absorb heavy metal pollutant. In other words, it potentially becomes an environmental-friendly fitoremediator of Pb in water.

Biological accumulation can occur through direct absorption on heavy metal in water and through food chain. Accumulation occurs due to the heavy metal tendency to form a complex substance with organic substance in organism body (Arsad and Said, 2013). Excessive lead consumption may damage brain and kidney, leading to death. It can also lead to miscarriage (Martin and Griswold, 2009).

Conclusion

Anthropogenic waste makes Pb pollutes the seaweed *G.verrucosa* pond. The present study found that Pb in sediment is higher than Pb in seaweed Pb in water, which is still within the quality standard. pH, salinity, and nitrite are the water quality parameters that can be used to determine the water quality. They can also depict the water quality characteristic. Water pH is the most dominant water quality parameter that affects Pb concentration in ponds

Acknowledgments

The authors would like to thank the head and staffs of Laboratory of Land resources of Faculty of Agriculture, Soedirman University, Purwokerto, and Integrated Laboratory of Fisheries and Marine of Pancasakti University, Tegal, Central Java, Indonesia for analyzing the sample of the study. We also would like to thank Journal reviewer.

References

Ambariyanto. 2011. *Water Pollution Biomonitoring.* Publisher Diponegoro University. Semarang pp.120 [in Indonesian].

Amin, B., Afriyani, E. and Saputra, M.A. 2011. Spatial Distribution of Pb and Cu metal in sediment and sea water in Tanjung Buton Water, Siak Regency, Riau Province. *Jurnal Teknobiologi.* 2 (1) : 1 – 8. [in Indonesian].

Arsad, M. and Said, I. 2013. [Accumulation of heavy metal of lead (Pb) in Mullets (*Liza melinoptera*) in Poboya Water]. *Jurnal Akademika Kimia.* 1 (4) : 187-192. [in Indonesian].

Aswadi, M. 2006. Fluctuation modeling of Nitrogen (Nitrite) in Palu river. *Jurnal SMARTek.* 4 (2) : 112 – 125. [in Indonesian].

Australian and New Zealand Environment and Conservation Council [ANZECC]. 2000. ANZECC interim Sediment Quality Guidlines. Report for The Environmental Research Institute of The Supervising Scientist, Sydney, Australia.

Appelo, C.A.J. and Postma, D. 1996. *Geochemistry, Groundwater and Pollution*. *A.A. Balkema. Rotterdam.* 536.

Aslan L.M.. 2006. *Seaweed Culture*. 7th edition. Publisher Kanisius. Yogyakarta. Pp.89.

Asni, A. 2015). [An Analysis of Seaweed (*Kappaphycus alvarezii*) Production Based on Season and Location Distancein Bantaeng Regency Water]. *Jurnal Akuatika.* 6 (2) : 140 – 153. [in Indonesian].

Astriandhita, K., Muljana, B., Winantris, Putra, P. S. and Praptisih, 2017. [Dynamics of Sediment Environment in Kaligarang, Semarang]. *Jurnal Riset dan Geologi.* 27 (2) : 169-177. [in Indonesian].

Ariyanti, D. and N. Intan, 2012. A Study of the Characteristics of Biopolymer *Gracillaria verrucosa* as The Absorption Material. *Jurnal Ilmu Lingkungan.* 10 (2) : 85 – 88. doi.org/10.14710/jil.10.2.85-88. [in Indonesian].

Ata, A., Nalcaci, O.O. and Ovez, B. 2012. Macro Algae *Gracilaria verrucosa* as a Biosorbent: : A Study of Sorption Mechanisms. *Algal Research*. 1: 194–204. doi:10.1016/j.algal.2012.07.001

Atmadja, W.S., Susanto, A. B. and Dhewani, N. 2012. *Seaweed (Makroalgae) Cultivation*. Publisher IFI. Jakarta. [in Indonesian].

Bhosale, U and K.C. Sahu, 1991. Heavy Metals and Pollution Arround The Island City of Bombay, India. Part II: Distribution of Heavy Metals Between Water, Suspended Particle and Sediment a Polluted Aquatic Regime. *Chemistry Geology*. 90 : 285-305.

Bonnin, E. P., Biddinger, E. J. and Botte, G. G. 2008. Effect of Catalyst on Electrolysis of Ammonia Efflents. *Journal of Power Sources.* 182 : 284-290

Burchett, 2002. Photosynthetic Pigments and Peroxides Activity as Indicators of Heavy Metal Stress in The Grey Mangrove *Avicennia marina* (Forsk.) Veirh. *Mar. Poll. Bull.* 42: 233-240.

Canadian Council of Ministers for The Environment (CCME). 2002. Sediment Quality Guidelines for the Protection of Aquatic Life Summary Table. CCME. Winnipeg, MB. 7p.

Connel, D.W., and G.J. Miller. 2006. *Chemistry and Ecotoxicology of Pollution*. Translated by Koestoer, Y. Publisher Diponegoro University. Jakarta. pp.520.

Chino, M. 1981. Uptake-Transport of Toxic Metals in Rice Plants. In :*Heavy Metal Pollution of Soils of Japan*. Eds. K. Kitagishi and I Yamane. Pp 81-94. Japan Scientific Societies Press, Tokyo

Dahuri, 2011. *Developing an Integrated Seaweed Industry.* Edition 93. Publisher Samudra. Jakarta. [in Indonesian].

Darmono, 2006. *Environment and Pollution: Their relationship with Toxicology of Metal Compound.* Publisher Diponegoro University. Jakarta. [in Indonesian].

Department of Maritime Affairs and Fisheries, 2011. *Techniques of Seaweed Gracillaria sp. and Euchemasp culture*. Regional Department of Marine and Fisheriesof Central Sulawesi. Palu. pp. 31. [in Indonesian].

Engledow, H.R and Bolton, J.J. 1992. Environmental Tolerances in Culture and Agar Content of *Gracilariaverrucosa* (Hudson) Papenfuss (Rhodophyta, Gigartinales) from Saldanha Bay. *S. Afr. J. Bot*. 58 (4) : 263 – 267.

Gerking, S.D. 1978. *Ecology of Freshwater Fish Production.* Halsted Press. New York.

Handhani, A.R. and Ambariyanto, E. Supriyantini, 2017. Reduction of Pb Concentration in Seawater by Seaweed *Gracilaria verrucosa*. *AACL Bioflux.* 10 (4) : 703-709. http://www.bioflux.com.ro/aacl.

Hardjojo, B. and Djokosetiyanto, 2005. *Water Quality Measurement and Analysis*. Open University Terbuka. Jakarta. [in Indonesian].

Heryanti, S., Setiari, N., Hastuti, B., Hastuti, E.D & Nurchayati, Y. 2009). [Physiological Response and Anatomy of Common Water Hyacinth (*Eichornia crassipes*) in Various Polluted Waters]. *J. Penelitian Sains Teknol.* 10 (1):30-40. [in Indonesian].

Hutagalung. H.P. 1991. *Marine Pollution by Heavy Metals. The Status of Marine Pollution in Indonesia and its Observation Techniques*. P3O-LIPI. Jakarta. [in Indonesian].

Hutagalung, H.P. 1997. *Analysis Methods of Sea Water, Sediment and Biota*. Book two. Jakarta: P3O-LIPI. I. Jakarta. 80 p. [in Indonesian].

Ihsan, Y.N., Aprodita, A., Rustikawati, I. and Pribadi, T.D.K. 2015. The Ability of *Gracillaria sp* as A Bioremediator in Absorbing Heavy Metal of Pb. *Jurnal Kelautan* 8 (1) : 10-18.

Indonesian National Standard, 2009. Maximum Level of Heavy metal contamination in Food. National Standardization Agency. Jakarta

Jiyah, B.Sudarsono dan A. Sukmono. 2017. [A Study of Total Suspended Solid (TSS) Distribution in Coastal Area. *Jurnal Geodesi Universitas Diponegoro* (1) : 41-47.

Kang and Z. Sui. 2010. Removal of Eutrophication Factors and Heavy Metal from a Closed Cultivation System using The Macroalgae, *Gracilaria sp.* (Rhodophyta). *Chinese Journal of Oceanology and Limnology.* 28 (6) : 1127-1130.

Kim, J.K., Kraemerc, G. and Ch. Yarishb, 2019. Evaluation of The Metal Content of Farm Grown *Gracilaria tikvahiae* and *Saccharina latissima* from Long Island Sound and New York Estuaries. *Algal Research.* 40 (101484) : 1-9. https://doi.org /10.1016/ j.chemosphere.2019.125636.

Koesbiono, 1980. *Marine Biology*. Faculty of Fisheries. Bogor Agricultural Institute. Bogor.

Komarawidjaya, W. 2003. Potential Use of Seaweed as Biofiltration agen in Polluted Brackish Water. *Jurnal Teknik Lingkungan.* 4 (3) : 155-159.

Komarawidjaya, W. 2005. Seaweed *Gracilaria sp* as The Fitoremedian of Organic Materials of Pond Water. *Jurnal Teknik Lingkungan P3TL-BPPT*. 6 (2) : 410-415.

Lobban, C. S. and Harrison, P. J. 1994. Seaweed Ecology and Physiology. Cambridge University Press, New York, 366 pp.

Martin, S. and Griswold, W. 2009. *Human Health Effect of Heavy Metals*. Kansas State University. 2(3) : 4-5.

Ma'ruf, W. F., Ibrahim, R., Dewi, E.N., Susanto, E. and Amalia, U. 2013. Seaweed *Caulerpa racemosa* and *Gracilaria verrucosa* as Edible Food. *Jurnal Saintek Perikanan*. 9 (1) : 68-74. [in Indonesian].

Maslukah. 2013. Relationship between Heavy Meta Pb, Cd, Cu, Zn and Organic Material and grain size in Sediment in Semarang West Flood Canal Estuary. Buletin Oseanografi Marina 2 (3) : 55-62. [in Indonesian].

Matos, J.S., Costa, A., Rodrigues, R. Pereira, and I.S. Pinto. 2006. Experimental Integrated Aquaculture of Fish and Red Seaweed in Northern Portugal. *Aquaculture.* (252) : 31-42.

Ministry of Environment. 2003. Minister of Population and Environment Regulation No. 115 of 2003, 10 July 2003 On Guideline for Determining Water Quality Status. Jakarta, pp.15.

Ministry of Environment. 2004. Minister of Population and Environment Regulation no. 51 of 2004 on Seawater Standard Quality. Ministry of Environment. Jakarta, pp.11.

Ministry of Environment. 2010. Minister of Environment Regulation No. 3 of 2010 on Waste Water Quality Standard for Industrial Area. Ministry of Environment. Jakarta, pp.7.

Neukermas, G.H., Loisel, X. Meriaux, R. Astoreca, and Mckee, D. 2012. *In situ* Variability of Mass - Specific Beam Attenuation and Backscattring of Marine Particles with Respect to Particle Site, Density and Composition. *J. Limnol. and Oceano*. 57 (1) : 124-144.

National Oceanic and Atmospheric Administration [NOAA]. 1999. Sediment Quality Guidelines Developed for National Status And Trends Program.

Nybakken, J.W. 1992. *Marine Biology: An Ecological Approach.* 3rd Ed. Harper Collins College Publishers. Patriqium, D.G. 1992. The origin of nitrogen and phosphorus for growth of the marine Angiosperm *Thalassia testudinium*. *Mar. Biol.* 15 : 35-46.

Ovez, B. 2006. Batch Biological Denitrification using *Arundo donax*, *Glycyrrhiza glabra*, and *Gracilaria verrucosa* as Carbon Source. *Process Biochemistry.* 41: 1289–1295.

Palar, H. 2012. Heavy Metal Pollution and Toxicology. PT. Rineka Cipta. Jakarta. 152 pp. [in Indonesian].

Payung, I. F. and Rusian. 2013. A study of The Content and Spatial Industry of Heavy Metal of Lead on Sediment and Clam (*Anadara sp*) in Coastal area of Makassar City. *Jurnal Kesehatan Lingkungan*. 2(5) : 30-45 [in Indonesian].

Perkins, E.J. 1974. The Biology of Estuarios and Coastal Waters. Academia Press. London

Ponggarang, D., Rahman, A. and Iba, W. 2013. The Effect Planting Space and Weight using Velticulture Method. *Jurnal Mina Laut Indonesia.* 3(12): 94- 112. [in Indonesian].

Purnamawati, F.S., Soeprobowati, T.R. and Izzati, M. 2015. Potential of*Chlorolla vulgaris* Beijerinckin Remediating Heavy metal Cd and Pb at Laboratory Scale. *Jurnal Bioma.* 16 (2) : 102-113.

Purwanto, 2005. Process and Environmental Manipulation Modeling. Edition I. Environmental Science Study Program, Postgraduate Program. Diponegoro University. Semarang 132 p. [in Indonesian].

Purwiyanto, A.I.S. 2015. Distribution and Adsorption of Heavy Metal (Pb) in Banyasin Downstream. *J. Ilmu Kelautan.* 20(3) : 153-162. [in Indonesian].

Puspitasari, Rachma. 2007). Laju Polutan dalam Ekosistem Laut. *Oseana.* Vol. XXXII (2), Hal. 21-28.

Puspitasari, Rachma. 2007). LajuPolutan dalam Ekosistem Laut. *Oseana,* Vol. XXXII (2), Hal. 21-28.

Puspitasari, R. 2007. Pollutant Rate in Sea Ecosystem. *Oseana.* XXXII (2) : 21-28. [in Indonesian].

Rakhman, Arif. 1999**.** A Study of Organic Material Distribution in Various Ecosystems in Bonebatang Island Water. Hasanuddin University, Makassar. [in Indonesian].

Raya, I. and Ramlah. 2012. Bioaccumulation of Ion Cd(II) IONS in Seaweed *Eucheuma cottoiin*. *Jounal Marine. Chim Acta.* 13 (2) : 13–19. [in Indonesian].

Reeves, R.D. 1992. The Hyperaccumulation of Nickel by Serpentine Plants *in* AJM Baker, J Proctor, RD Reeves (Eds.), The Vegetation of Ultramafic (Serpentine) Soils, Intercept Ltd., Hampshire, pp. 253-277

Rohman, A., Wisnu, R. and Sri Rejeki. 2018. Determining the Suitability of Muara Gembong Coastal Area for Seaweed Culture using Geographic Information System (SIG). *Jurnal Sains Akuakutur Tropis*. 2 (1) : 73-82.

Rubio, C., Napoleone, G., Luis-González, G., Gutiérrez, A.J. and González-Weller, D. and Hardisson, A. and Revert, C. 2017. Metals in Edible Seaweed. *Chemosphere*. 173 : 572-579. https://doi.org/10.1016/j.chemosphere.2017.01.064

Shimoda, T., Suryati, E. and Ahmad, T. 2006. Evaluation in Shrimp Aquaculture System using Mangrove, Oyster and Seaweed as Biofilter Based in The Concentration of Nutrient and Chlorophila. *JARG.* 40 (2): 189–193.

Siaka, I.M., A.iSuastuti, N.G.A.M. D. and Mahendra, I.P. B. 2016. Heavy metal Pb and Cu distribution in Seawater, Sediment, and Seaweed in Pandawa water. *Jurnal Kimia.* 10 (2) : 190-196. [in Indonesian].

Sitorus, H. 2004. An Analysis of Heavy Metal of Lead Accumulation in Blood Clam in East Coastal Area of North Sumatera. *Jurnal Ilmu-ilmu Pesisir and Perikanan Indonesia*. 11 (1) : 53-60. [in Indonesian].

Simanjuntak, M. 2012. Sea water quality based on Nutrient, Dissolved Oxygen, and pH in Banggai Water, Central Sulawesi. *Jurnal Ilmu dan Teknologi Kelautan Tropis.* 4: 290-303. [in Indonesian].

Simpson, S.L., Maher, E.J. and Jolley, D.F., 2004. Processes Controlling Metal Transport and Retention as Metal-Contaminated Groundwaters Efflux through Estuarine Sediments. *Chemosphere*. 56 : 821-831.

Soemirat, J. 2005. Environmental Toxicology. Publisher Gadjah Mada University. Yogyakarta. [in Indonesian].

Soelistyowati, D. T., [in Indonesian].I. A. A. D., Murni, dan Wiyoto. 2014. Morphology of *Gracilaria* sp. Cultured in Ponds in Sederhana Beach, Muara Gembong. *Jurnal Akuakultur Indonesia.* 13(1) : 94-104. [in Indonesian].

Sri Puryono, S. Anggoro, Suryanti and Anwar, I.S. 2019. Ecosystem-based Coast and Sea Management. Publisher Diponegoro University. Semarang pp.270.

Sunarto. 2009). Role of Light in Production Process in Sea. Ministry of Marine Affairs and Fisheries. Diponegoro University. Semarang. [in Indonesian].

Suryono, C. A. 2016. Antropogenic Heavy metal (As, Hg, Cr, Pb, Cu dan Fe) pollution in Coastal Area in Tugu City, Central Java. *Jurnal Kelautan Tropis* 19(1) : 37 – 42. doi.org/10.14710/jkt.v19i1.598. [in Indonesian].

Susilowati, T., Rejeki, S., Dewi, E. N. and Zulfitriani, 2012. The Effect of Depth on the Growth of Seaweed *(Eucheuma cottonii)* Cultured Using Longline Method in Mlonggo Beach, Jepara Regency. *Jurnal Saintek Perikanan.* 8(1) : 7-12. [in Indonesian].

Swedish Environmental Protection Agency (SEPA). 2000. Environmental Quality Criteria Coasts and Seas. Aralia. Sweden.

Valderrama, D., Cai, J., Hishamunda, N. and Ridler, N. 2013. Social and Economic Dimensions of Carrageenan Seaweed Farming. Fisheries and Aquaculture Technical Paper No. 580). Rome, FAO. 204 pp.

Waldichuk. 1974. Some Biological Concern in Heavy Metals Pollution in: Verbergand Venbeg (eds), Pollution and Physiology of Marine Organism, Academic Press, London. 157 p.

Wardhana, A.W. 2001. *The Effect of Environmental Pollution.*

Publisher Andi, Yogyakarta. 459 hal. [in Indonesian].

Whyte, J.N., Englar, J.R., Saunders, R.G. and Lindsay, J.C. 1981. Seasonal Variations in the Biomass, Quantity and Quality of Agar, from the Reproductive and Vegetative Stages of *Gracilaria verrucosa type*). Bot Mar 23 : 493–501.

Widiastuti, I.M. 2011. Production of *Gracilaria verrucosa* Cultured in Pond with Different Seed Weight and Planting Distances. *J. Agrisains.* 12 (1): 57-62. [in Indonesian].

Wood, M. S. 1987. *Subtidal Ecology.* Edward Amoldy Limited. Australia.

Xi Xiao, S., Agusti, F., Lin, K. Li, Y. Pan, Y.Yu, Y. Zheng, J.Wu and Duarte, C. M. 2017. Nutrient Removal from Chinese Coastal Waters by Large-Scale Seaweed Aquaculture. *Scientific Reports*. 7 : 46613 : 1-6..

Yulianto, B., Ario, R. and Agung, T. 2006. Seaweed *Gracilaria sp* absorption ability of Copper (Cu) as Biofilter. *Jurnal Ilmu Kelautan II* (2) : 72-78. [in Indonesian].

Yulianto, B, R., Pramesti, R.i Hamdani, Sunaryo and A. Santoso, 2018). Absorption Capacity and Growth of Seaweed *Gracilaria sp*. in the Media that Contains Heavy Metal of Cadmium (Cd). *Jurnal Kelautan Tropis.* 21 (2) : 129–136. doi.org/10.14710/jkt.v21i2.3849. [in Indonesian].

Yun, P. S., Ariffin, J., Siang, H. Y. and Tahir, N. 2015. Influence of Monsoon on the Distribution of Organic Carbon in Inner Continental Shelf Core Sediments, South China Sea, Malaysia. *Sains Malaysiana.* 4 (7): 941–945.