Effectivenes of *Halimeda* sp. as a marine bioremediation agent for heavy metal (lead and cobalt) contamination

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Abstract. Industrial development poses a serious threat to marine ecosystems and biota in Indonesia. Waste released into the environment includes inorganic substances such as heavy metals Lead (Pb) and Cobalt (Co). An effort to restore contaminated environments is bioremediation using *Halimeda* sp. It is an alga capable of acting as a bioremediation agent through phytoremediation. This study aimed to determine the effectiveness of *Halimeda* sp. as a bioremediation agent for seawater contaminated with the heavy metals Lead (Pb) and Cobalt (Co). The study was conducted at a laboratory scale by culturing *Halimeda* sp. algae in 500 ml glass jars with heavy metal concentrations of 1.5, 3, and 6 ppm. The results of heavy metal content testing showed that *Halimeda* sp. are capable of absorbing heavy metals. Lead (Pb) absorption at concentrations of 1.5, 3, and 6 ppm was 87.83%, 90.17%, and 98.50%, respectively, and Cobalt (Co) absorption at the same concentrations was 99.17%, 98.40%, and 98.01%, respectively. These test results indicate that *Halimeda* sp. has a high potential for remediating heavy metal Lead (Pb) by bioaccumulation via absorption.

Keywords: Bioremediation, *Halimeda* sp., heavy metal

1 Introduction and background

The rapid pace of industrial development must be carefully monitored to maintain balance in human life. Although industrial projects offer positive economic impacts, many still disregard environmental sustainability, posing a threat to the ecosystem and marine biota in Indonesia. Industrial waste discharged into the environment includes inorganic materials such us as heavy metals like Lead (Pb) and Cobalt (Co). According to [1], heavy metal pollution in Indonesia tends to increase in line with rising industrialization. Heavy metals are

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key indicators of the quality of aquatic environments. When present above threshold levels, these metals can have detrimental effects on aquatic ecosystems and human health [2]

Low concentrations of cobalt (Co) play an important role in promoting the growth of algae and higher plants. However, Co is toxic at high concentrations [3]. A study by [4] reported that sediments along the coastal area of Bandar Lampung were contaminated with Co levels exceeding the established environmental quality standards. The analysis revealed cobalt concentrations ranging from 298.346 ± 3.309 ppm to 258.639 ± 1.103 ppm, and cadmium (Cd) concentrations ranging from 7.413 ± 0.009 ppm to 7.221 ± 0.008 ppm. These values exceed the quality threshold set by the National Sediment Quality Survey (USEPA) and Ontario Ministry of the Environment.

Research by [5] stated that Lampung Province hosts a well-developed industry for processing anchovies and green mussels, with production reaching up to 8 tons per year. The study also indicated that Lampung waters are polluted, surpassing water quality limits, which poses risks to public health. The heavy metals contaminating Lampung waters include Lead (Pb) and Copper (Cu), with concentrations of 0.63 mg/L and 0.14 mg/L, respectively. According to Government Regulation No.22 of 2021, the quality standards for Lead (Pb) and copper (Cu) are 0.05 mg/L. Lead (Pb), in particular, is a significant environmental threat. It originates from household waste and mining discharge, which threatens the balance of marine ecosystems [6]. This environmental degradation highlights the need for strategic remediation. Several traditional and modern methods are available for removing heavy metals.

Traditional and modern techniques have been employed to eliminate heavy metals from contaminated marine environments. Traditional techniques include ion exchange, electrochemical treatments, osmosis, evaporation, and precipitation. However, these methods often require complex indicators, which makes the process challenging. Modern and environmentally friendly approaches have been developed to overcome this problem. One such method is phytoremediation, which involves the use of algae to remove water pollutants. The green alga *Halimeda* sp. is capable of acting as a bioremediation agent through phytoremediation [7] and is a promising strategy for reducing heavy metal concentrations in water using algae, which are abundant, low-cost, and can yield value-added products. Algae can effectively adsorb heavy metal ions from polluted areas, a capability known as biosorption [8].

Halimeda sp. are a genus of green algae commonly found in tropical and subtropical waters [9]. According to [10], the waters of Pahawang Island are well-known tourist destinations in Lampung Province. Tourism-related activities such as boat anchoring and infrastructure construction may facilitate the growth of various macroalgae. Research by [11] indicates that small islands have tourism potential but are vulnerable to environmental changes. [12] found that continuous tourist visits to Pahawang Island could damage its natural resources. This is consistent with [13], who stated that environmental pressure increases with increasing visitor numbers and expanding infrastructure to meet tourist demand. Coastal activities, such as boat painting, cleaning, welding, boat building, and fuel use also contribute to heavy metal pollution [14]. The objectives of this study were as follows:

- To determine the effects of Lead (Pb) and Cobalt (Co) concentrations on the biosorption capacity of *Halimeda* sp.
- To identify which heavy metals pollutans, lead (Pb) or Cobalt (Co), is more effectively remediated by *Halimeda* sp.

A previous study [15] demonstrated that algae can serve as bioremediation agents for heavy metals. Specifically, *Glaciaria* sp. was found to absorb lead (Pb) over a 144-hour experiment at room temperature. Therefore, research on the effectiveness of *Halimeda* sp. in remediating lead (Pb) and cobalt (Co) in contaminated marine environments may provide new insights for supporting sustainable marine ecosystem recovery and could serve as a basis for algae-based bioremediation recommendations, particularly in heavy metal-contaminated coastal tourism areas such as Pahawang Island.

2 Methodology

The details of the methodology of this study consist of several research stages, as outlined below.

2.1 Time and location of research

Sample collection in this study was conducted on Pahawang Island, Marga Punduh Subdistrict, Pesawaran Regency, Lampung Province. The research was conducted at the Marine Environmental Science Laboratory, Institut Teknologi Sumatera. The study was conducted from October 2024 to January 2025, covering the sample collection and data processing phases. The heavy metal content analysis was conducted at the Integrated Laboratory and Technology Innovation Center of the University of Lampung. The sample collection site map used in this study is shown in **Fig. 1.**

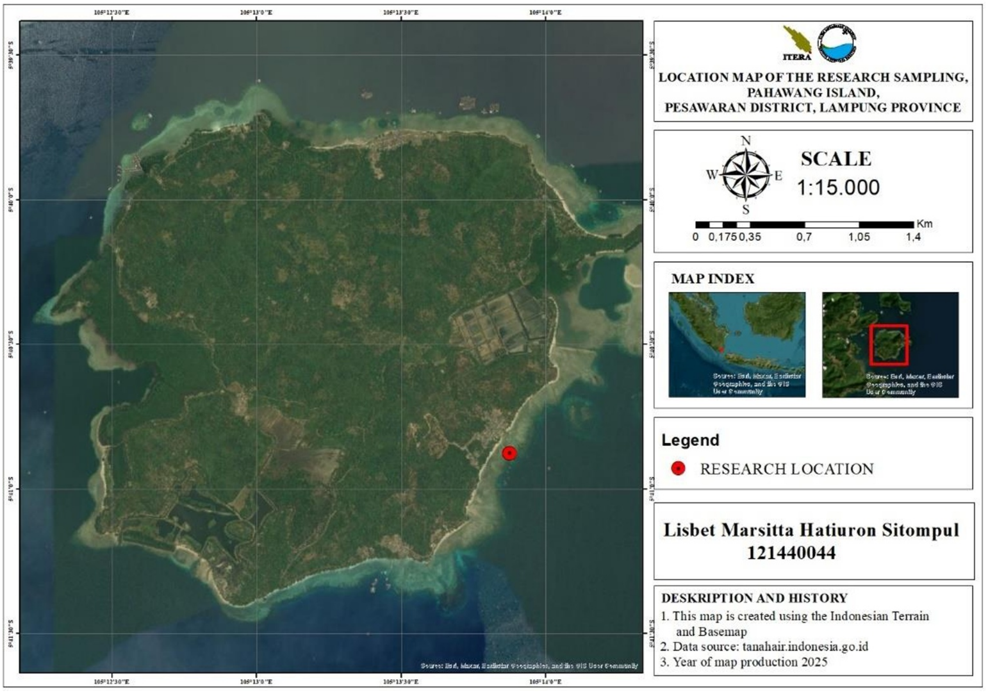

Fig. 1. Sample collection location.

2.2 Tools and materials of the researh

The tools and materials used in this study are presented in **Table 1** and **Table 2**.

Table 1. Tools of the research.

Tool Name	**Function**
Glass jar	Container for algae treatment; 500 mL capacity
Aerator	Supplies oxygen for algae in the glass jar
Iron rack	Holds treated glass jars
UV lamp	Provides light for algae photosynthesis
UV filter cotton	Filters large particles and debris from water before UV exposure
Plastic wrap	Seals the aerator with the glass jar
Tape	Attaches labels to the glass jars
Scissors	Cuts tape or label paper as needed
Ruler	Measures algae length in each glass jar
Tweezers	Places algae in the jars and aids in metal weighing
Spatula	Aids in weighing heavy metals on analytical balance
Analytical balance	Weighs heavy metals to be used
Aluminum foil	Holds the metals during weighing on the analytical balance
Measuring cylinder	Measures the volume of seawater used
Label	Marks each treatment on the jars
ICP-OES	Tests the concentration of Lead (Pb) and Cobalt (Co)
Aquarium	Holds algae after sampling and prior to heavy metal treatment
Digestion flask	For digesting samples prior to metal content testing
Whatman No. 41 filter paper	Filters cooled samples
Heavy metal digester	Instrument used for sample digestion
pH Meter, Refractometer, and Thermometer	Measure physical parameters during the research

Table 2. Materials of the research.

Material Name	**Function**
Sterile seawater	Medium to which heavy metals will be added
Distilled water (Aquadest)	Used for calibrating equipment
Cobalt (Co)	Heavy metal introduced into seawater
Lead (Pb)	Heavy metal introduced into seawater
***Halimeda* sp. Algae**	Subject of the study
Ultrapure water	Adjusts sample volume to 10.0 mL

2.3 Research procedure

2.3.1. Sample collection

Halimeda sp. algae samples were collected from the waters surrounding Pahawang Island using purposive sampling based on specific criteria [16]. The algae were collected along with the substrate in sufficient quantities to avoid damaging the ecosystem. Samples were placed in Ziplock bags and stored in cool boxes for transport to the Marine Environmental Science Laboratory at ITERA.

2.3.2. Experimental procedure

We define an experiment as a scientific procedure in which the object of study is subjected to interventions (manipulations), with the aim of obtaining predictable results. The author

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emphasized the epistemological differences between experimental and non-experimental observations [33].

(A) Algal Acclimatization

The collected *Halimeda* sp. algae were cleaned of associated organisms. A total of 750 g was weighed and placed in a 30x23x18 cm aquarium. An aerator and 10 liters of sterile seawater were added. Sterile seawater refers to filtered seawater free of contaminants. An aquarium was placed near a window to allow light for photosynthesis. Acclimatization was conducted for one week prior to the treatment phase, based on the method described in [17]. Culture media were adjusted to support *Halimeda* sp. growth with salinity 15–32 ppt, pH 6.3–10, and temperature 15–30°C [18]. [19] also reported optimal growth at 30°C.

(B) Heavy Metal Treatment (Lead and Cobalt)

Following successful acclimatization, 650 g of algae were used in the treatment phase. Glass jars (500 mL) were filled with 400 mL sterile seawater, aerators, and *Halimeda* sp. algae (6 cm in length). Different concentrations of heavy metals were added to the jars and a plastic wrap was used to reduce evaporation. The metals were weighed using an analytical balance.

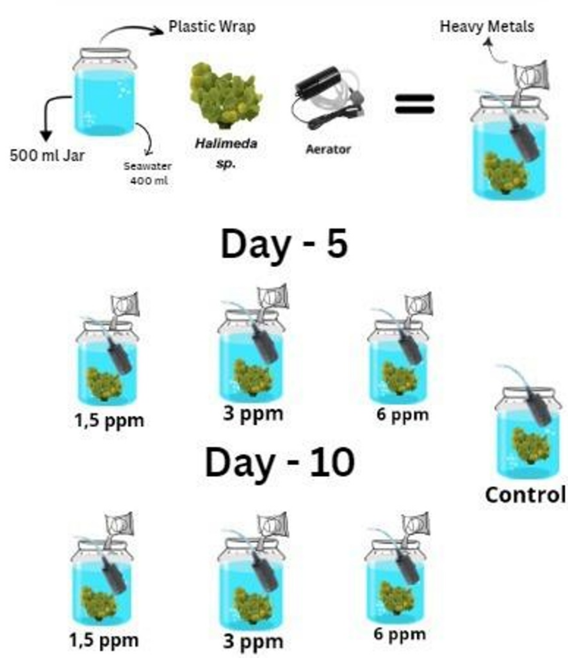

Fig. 2. Ilustration of treatment.

Three concentrations of heavy metals were used: 1.5, 3, and 6 ppm, based on [20], who reported that *Chlorophyta* spp. could remediate up to 80% of the heavy metals. Thus, this study applied double concentrations to evaluate the biosorption capacity. Remediation efficacy was evaluated on Days 5 and 10. The experimental setup is shown in **Fig. 2.**

In the heavy metal process, each glass jar was labeled to identify the corresponding experimental treatment. Lists the labels and their descriptions are presented in **Tabel 3** below.

Table 3. Label Information.

Label	Description
A	Control
B	Lowest metal concentration (1.5 ppm)
C	Medium metal concentration (3 ppm)
D	Highest metal concentration (6 ppm)

(C) Heavy Metal Content Analysis (Lead and Cobalt)
The capacity of *Halimeda* sp. to remediate Pb and Co was analyzed using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) following the sample preparation procedures from [21].

1. Add 10 mL of sample into a digestion flask, then add 0.2 mL of HNO_3 and 0.1 mL of HCl.
2. The samples were digested using a heavy metal digester at 95°C for 15 min.
3. The sample was cooled, filtered through Whatman No. 41 paper, and adjusted to 10.0 mL using ultrapure water.
4. Optimize ICP-OES wavelength: 220.353 nm for Pb and 238.204 nm for Co.
5. Analyzing samples using ICP-OES Equations should be centered and should be numbered with the number on the right-hand side.

2.3.2. Data analysis

This study aimed to evaluate the effectiveness of *Halimeda* sp. as a bioremediation agent for Pb and Co. The effectiveness was calculated using the formula from [22].

$$H = Co - Cs \qquad (1)$$

$$F = \left(\frac{H}{Co}\right) \times 100\% \qquad (2)$$

Where H is the concentration of Pb and Co remediated by *Halimeda* sp., Co is the Initial concentration of Lead (Pb) and Cobalt (Co), Cs is the final concentration after separation from *Halimeda* sp., and F is the percentage reduction in heavy metal concentration.

3 Results and discussion

3.1. Acclimatization phase of *Halimeda* sp.

This study was conducted to determine the effectiveness of *Halimeda* sp. in binding to heavy metal ions. Several stages were involved in the laboratory to evaluate the effectiveness of *Halimeda* sp. against heavy metals. These stages began with the preparation phase (acclimatization) and continued through heavy metal testing. Acclimatization is the preparation or adaptation phase of *Halimeda* spp. prior to exposure to heavy metals. It is the physiological adaptation process of an organism to a new environment, encompassing behavior, morphology, and biochemical metabolic pathways within its body [23]. This preparation stage is essential to ensure the readiness of *Halimeda* sp. for treatment and to prevent mortality before heavy metal exposure.

In this study, 585 g of *Halimeda* sp. out of 750 g successfully underwent acclimatization. Acclimatization was carried out to enhance the tolerance of *Halimeda* sp. to stress induced by heavy metals, enabling the algae to survive and perform their biological functions during the bioremediation of heavy metals.

Fig. 3. *Halimeda* algae after the acclimatization process is completed.

3.2. The Influence of physical and chemical parameters on the absorption of lead (Pb) and cobalt (Co) by *Halimeda* sp.

Physical parameters, such as temperature, and chemical parameters, including pH and salinity, are crucial indicators in studies concerning heavy metal absorption. The pH, temperature, and salinity are important indicators of water quality. Water quality is a key factor influencing the growth and development of macroalgae [24]. The results of several physical and chemical parameters based on the present study are shown in **Table 4 - 6**.

Table 4. Measurement of physical and chemical parameters on day 0.

Treatment	Sample	pH	Temperature	Salinity
A (Kontrol)	-	8.47	29°C	33
B (1,5 ppm)	Pb	8.48	29°C	33
	Co	8.48	29°C	33
C (3 ppm)	Pb	8.48	29°C	33
	Co	8.48	29°C	33
D (6 ppm)	Pb	8.49	30°C	33
	Co	8.49	30°C	33

Table 5. Measurement of physical and chemical parameters on day 5.

Treatment	Sample	pH	Temperature	Salinity
A(kontrol)	-	8.47	29°C	33
B (1,5 ppm)	Pb	8.47	30°C	34
	Co	8.48	29°C	33
C (3 ppm)	Pb	8.47	30°C	34
	Co	8.48	29°C	33
D (6 ppm)	Pb	8.47	30°C	34
	Co	8.47	30°C	33

Table 6. Measurement of physical and chemical parameters on day 10.

Treatment	Sample	pH	Temperature	Salinity
A(Kontrol)	-	8.47	29°C	33
B (1,5 ppm)	Pb	8.46	30°C	34
	Co	8.47	29°C	34
C (3 ppm)	Pb	8.45	30°C	34
	Co	8.46	29°C	33
D (6 ppm)	Pb	8.44	30°C	34
	Co	8.45	30°C	33

According to the Government Regulation of the Republic of Indonesia No. 22 of 2020 concerning the Implementation of Environmental Protection and Management, the quality standards for physical parameters in marine waters are as follows: temperature between 28 °C and 30 °C, salinity between 33 ppt and 34 ppt, and pH ranging from 6.5 8.5. Based on the measurement results of the physical parameters (temperature, pH, and salinity) in this study, the recorded values remained within the acceptable limits. The recorded temperature was between 29 Â °C and 30 Â °C, pH ranged from 8.45 to 8.49, and salinity between 33 ppt and 34 ppt.

Temperature, pH, and salinity are some of the most important indicators of macroalgal growth. Temperature was measured using a thermometer on days 0, 5, and 10. The obtained temperatures ranged from 29 to 30 °C. An increase in temperature can influence the rate of heavy metal absorption, as temperature affects metabolic rates, such as enzymatic activity and active transport. Active transport utilizes the energy derived from photosynthesis [25]. Excessively high temperatures may induce stress in macroalgae by affecting physiological processes such as photosynthesis, respiration rate, growth, and reproduction. In general, macroalgae can thrive at temperatures ranging from 24 to 30 °C.

Salinity and pH measurements were conducted thrice: at the beginning of the experiment, on day 5, and on day 10. Salinity was measured using a refractometer, and pH was measured using a pH meter. The pH recorded in this study ranged from 8.45 to 8.49. Waters with pH ranging from 6.5 to 7.5 are considered productive, while those with pH values between 7.5 and 8.5 are classified as highly productive. The salinity values ranged from 33 to 34 ppt. Variations in salinity measurements during the study were likely due to evaporation occurring in each treatment, which is a common phenomenon observed in similar research. Extremely low or high salinity levels may impair macroalgal growth [26].

3.3 Heavy metal absorption of lead (Pb) and cobalt (Co) by *Halimeda* sp.

The results of the heavy metal absorption tests of lead (Pb) and cobalt (Co) by *Halimeda* sp. indicate that *Halimeda* sp. is capable of remediating these heavy metals, as evidenced by the decrease in heavy metal concentrations at each tested level. The percentage of metal absorbed by *Halimeda* spp. varied. The absorption percentage of Lead (Pb) increased with increasing concentrations, whereas the absorption percentage of Cobalt (Co) decreased as its concentration increased. The results of the heavy-metal absorption tests are presented in **Tables 7 - 9.**

Table 7. Absorption of Lead (Pb) and Cobalt (Co) by *Halimeda* sp. at a concentration of 1.5 ppm

Time	Heavy Metal	Initial (mg)	Final (mg)	Total Reduction (mg)	Reduction (%)
Day 5	Pb	0.6	0.115	0.485	80.83%
	Co	0.6	0.026	0.574	95.72%
Day 10	Pb	0.6	0.073	0.527	87.83%
	Co	0.6	0.005	0.595	99.17%

Table 8. Absorption of Lead (Pb) and Cobalt (Co) by *Halimeda* sp. at a concentration of 3 ppm.

Time	Heavy Metal	Initial (mg)	Final (mg)	Total Reduction (mg)	Reduction (%)
Day 5	Pb	1.2	0.132	1.068	88.99%
	Co	1.2	0.021	1.179	98.21%
Day 10	Pb	1.2	0.118	1.082	90.17%
	Co	1.2	0.019	1.181	98.40%

Table 9. Absorption of Lead (Pb) and Cobalt (Co) by *Halimeda* sp. at a concentration of 6 ppm.

Time	Heavy Metal	Initial (mg)	Final (mg)	Total Reduction (mg)	Reduction (%)
Day 5	Pb	2.4	0.083	2.317	96.56%
	Co	2.4	0.054	2.346	97.77%
Day 10	Pb	2.4	0.036	2.364	98.50%
	Co	2.4	0.048	2.352	98.01%

The percentage of Lead (Pb) absorption by *Halimeda* sp. at a concentration of 1.5 ppm was 80.83% on day 5 and increased to 87.83% on day 10. At 3 ppm, the absorption increased to 88.99% on day 5 and 90.17% on day 10. At the highest concentration (6 ppm), the Lead (Pb) absorption by *Halimeda* sp. increased in proportion to the initial concentration, reaching 96.55% on day 5 and 98.50% on day 10.

The absorption of cobalt (Co) by *Halimeda* sp. at the lowest concentration of 1.5 ppm was 95.71% on day 5 and 99.17% on day 10. At 3 ppm, the absorption rates were 98.21% and 98.40% on Days 5 and 10, respectively. At 6 ppm, the absorption was slightly lower, with values of 97.77% on day 5 and 98.01% on day 10. Although daily absorption increased over time, higher concentrations of cobalt (Co) led to a slight decrease in absorption percentage, as shown by the lower values at 6 ppm compared to 1.5 ppm on day 10.

The results of the heavy metal absorption tests showed a notable reduction in heavy metal content. At 1.5 ppm, the initial concentration of 0.6 mg/L decreased to 0.073 mg/L for Lead (Pb) and 0.005 mg/L for Cobalt (Co) by day 10, corresponding to reductions of 0.527 mg/L and 0.595 mg/L, respectively. At 3 ppm, the concentration decreased from 1.2 mg/L to 0.118 mg/L for Lead and 0.019 mg/L for Cobalt, with total reductions of 1.082 mg/L and 1.181 mg/L, respectively. At 6 ppm, heavy metal concentrations dropped from 2.4 mg/L to 0.036 mg/L for Lead and 0.048 mg/L for Cobalt, with total reductions of 2.364 mg/L and 2.352 mg/L, respectively.

The reduction in heavy metal concentrations suggests that biosorption occurred. The functional groups in *Halimeda* sp. are capable of binding to Lead (Pb) and Cobalt (Co) ions. The ability of algae to absorb heavy metals is influenced by both the exposure time and the metal concentration in the water [27]. The results indicate that the percentage of Cobalt (Co) absorption by *Halimeda* sp. was generally higher than that of Lead (Pb). However, as Cobalt concentration increased, the absorption efficiency of *Halimeda* sp. decreased.

3.4. The effect of lead (Pb) heavy metal concentration on the biosorption by *Halimeda* sp.

In the biosorption test of Lead (Pb) heavy metal by *Halimeda* sp., three different concentrations were used: 1.5, 3, and 6 ppm. The results indicated that the absorption of Lead (Pb) increased proportionally with increasing concentrations of the heavy metal. Based on the test data, *Halimeda* sp. demonstrated the ability to remediate up to 80.33% of heavy metals. When the concentration was doubled to 3 ppm, the absorption efficiency increased to 90.17% and the highest absorption was observed at a concentration of 6 ppm, reaching 98.50%. The increasing percentage of Lead (Pb) absorption by *Halimeda* sp. with higher metal concentrations is attributed to the increased surface area and pore volume available for biosorption due to the higher metal dose [28]. The percentage of Lead (Pb) absorption by *Halimeda* sp. is shown in **Fig. 4**.

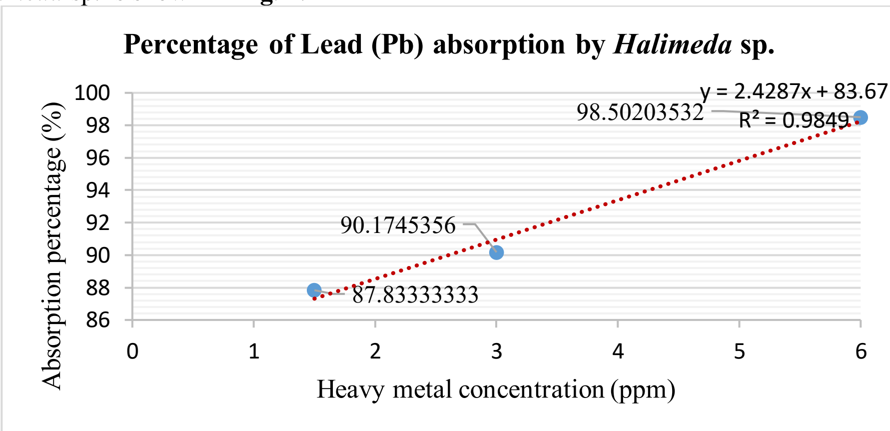

Fig. 4. Percentage of Lead (Pb) Absorption by *Halimeda* sp.

The graph of Lead (Pb) absorption by *Halimeda* sp. displays a linear regression equation of $y = 2.4287x + 83.67$, with a coefficient of determination (R^2) of 0.9849. This indicates that for every 1 ppm increase in Lead (Pb) concentration (x), the percentage of Pb absorption (y) increases by an average of 2.4287%. An R^2 value of 0.9849 suggests that the regression model is highly accurate.

As the initial metal concentration increased, the value of the heavy metal absorption also increased. According to [28], the biosorption capacity is directly proportional to increasing metal concentration. This is related to the enhancement of total ionic transfer, leading to an increase in metal ion adsorption. This finding is supported by the studies of [29] and [30], which stated that Chlorella sp. is capable of absorbing heavy metal ions at a concentration of 10 mg/L, with absorption increasing at concentrations of 50–100 mg/L. During biosorption, chemical adsorption occurs via the formation of bonds with various functional groups (hydroxyl, carboxyl, and amino groups). Among these, the carboxyl group (-COOH) plays a more dominant role in the absorption of heavy metals than the hydroxyl groups (-OH) because of its stronger negative charge. Carboxyl groups (-COOH) are weak acids that easily release H^+ ions, whereas amino groups ($-NH_2$) are weak bases that can capture H^+ ions.

3.5. The effect of cobalt (Co) heavy metal concentration on the biosorption by *Halimeda* sp.

The results of heavy metal testing indicated that the percentage of cobalt (Co) heavy metal absorption by *Halimeda* sp. was higher than that of Lead (Pb). This is presented in **Tables 7–9**, which show that the percentage of Cobalt (Co) absorption at a concentration of 1.5 ppm reached 99.17%. This phenomenon is presumably influenced by the atomic radius of the heavy metal ions, which can affect the bond strength between the functional groups on the algae and the metal ions.

The atomic radius of Lead (Pb) is 175 pm, whereas that of Cobalt (Co) is 125 pm. The shorter the atomic radius, the more stable and stronger is the resulting bond [31]. Because the atomic radius of Cobalt (Co) is smaller than that of Lead (Pb), it forms stronger bonds. However, as the concentration of cobalt (Co) increased, its absorption decreased —at 3 ppm, the absorption was 98.40%, and at 6 ppm, it decreased to 98.01%. This may be due to the availability of active adsorption sites on the biosorbent surface, which are abundant at low concentrations. As the concentration of Cobalt (Co) increases, these active sites become increasingly occupied, leading to a decline in the adsorption capacity. The deceleration of the absorption process is caused by the reduction of active sites on the biosorbent surface, which eventually results in saturation and repulsion forces between the molecules in the solution and biosorbent [31]. As long as the number of active sites on the adsorbent surface did not reach the optimum adsorption capacity, the percentage of heavy metal absorption continued to increase.

The decrease in Cobalt (Co) absorption by *Halimeda* sp. with increasing metal concentration occurs because the adsorption capacity of the biosorbent has reached its maximum, meaning that the number of metal ions in the solution exceeds the available adsorbent particles, resulting in saturation [31]. The percentage of Cobalt (Co) heavy metal absorption by *Halimeda* sp. is shown in **Fig. 5**.

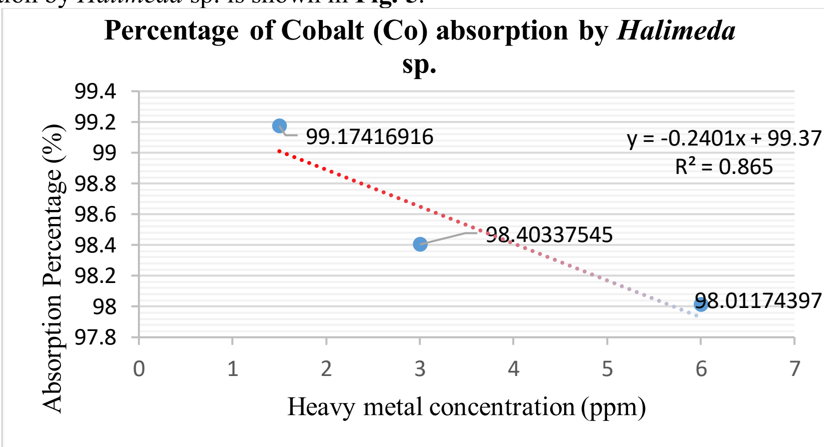

Fig. 5. Percentage of Cobalt (Co) Absorption by *Halimeda* sp.

The graph of cobalt (Co) absorption by *Halimeda* sp. exhibits a linear regression equation of y = -0.2401x + 99.37, with a coefficient of determination (R^2) of 0.865. This regression indicates that for each 1 ppm increase in Cobalt (Co) concentration (x), the percentage of absorption (y) decreases by approximately 0.2401%. An R^2 value of 0.865 suggests that the regression model is both accurate and valid. Based on the results of this study, the percentage of cobalt (Co) absorption by *Halimeda* sp. at 1.5 ppm of 99.17%. At concentrations of 3 ppm and 6 ppm, the absorption percentage decreased. This suggests that the saturation point for Cobalt (Co) absorption by *Halimeda* sp. in this study occurred at 1.5 ppm. According to the Langmuir model, the maximum heavy metal absorption capacity by algal biomass is 17.98 mg/g [32].

4. Conclusion

Based on the results and discussion of study, it can be concluded that:

1. The application of Lead (Pb) heavy metal concentrations influences the biosorption capacity of *Halimeda* sp., where higher concentrations of Lead (Pb) result in increased biosorption capacity. This is demonstrated by the percentage of Lead (Pb) absorption at concentrations of 1.5, 3, and 6 ppm on day 10, which were 87.83%, 90.17%, and 98.50%, respectively. Conversely, the application of cobalt (Co) heavy metal concentrations affects the biosorption capacity of *Halimeda* sp. in a decreasing manner, where higher concentrations lead to reduced biosorption. This is shown by the percentage of cobalt (Co) absorption at concentrations of 1.5, 3, and 6 ppm on day 10, which were 99.17%, 98.40%, and 98.01%, respectively.

2. The absorption of Lead (Pb) by *Halimeda* sp. was more effective than the absorption of Cobalt (Co), as indicated by the increasing absorption percentage of Lead (Pb) at higher concentrations, whereas the absorption percentage of Cobalt (Co) decreased with increasing concentrations. Therefore, *Halimeda* sp. demonstrates high potential as a bioremediation agent for marine environments contaminated with Lead (Pb) heavy metal

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