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A REVIEW: SEAWEEDS POTENTIAL AS METAL ABSORPTION AGENTS IN AQUATIC ENVIRONMENTS

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ABSTRACT

Heavy metal pollution in aquatic environments is an issue that threatens aquatic ecosystems. One natural solution to overcome this problem is to utilize seaweed as a heavy metal absorbing agent. Seaweed is capable of absorbing heavy metals such as cadmium (Cd), lead (Pb), arsenic (As), copper (Cu), and zinc (Zn) through interactions on their cell walls. Types of seaweed that have been studied by many researchers such as *Gracilaria sp., Caulerpa racemosa, Ulva sp., Pandina australis, Kappaphycus alvarezii, Codium fragile* and *Eucheuma spinosum* have demonstrated varying but significant effectiveness in absorbing heavy metals. It can be concluded that seaweed has great potential to be used as an environmentally friendly absorbing agent and can serve as a bioindicator of aquatic environment quality.

Keywords: Heavy metals, seaweed, environment, waters

ABSTRAK

Pencemaran logam berat di lingkungan perairan merupan isu yang mengancam ekosistem perairan. Salah satu solusi alami dalam mengatasi permasalahan tersebut dengan pemanfaatan rumput laut sebagai agen penyerap logam berat. Rumput laut dapat menyerap logam berat seperti kadmium (Cd), timbal (Pb), arsenik (As), tembaga (Cu), dan seng (Zn) melalui interaksi pada dinding selnya. Jenis rumput laut yang telah diteliti banyak peneliti seperti Gracilaria sp., Caulerpa racemosa, Ulva sp., Pandina australis, Kappaphycus alvarezii, Codium fragile dan Eucheuma spinosum menunjukan efektivitas yang bervariasi namun signifikan dalam menyerap logam berat. Dapat disimpulkan bahwa rumput laut memiliki potensi besar untuk dimanfaatkan sebagai agen penyerap yang ramah lingkungan dan dapat dijadikan bioindikator terhadap kualitas lingkungan perairan

Kata kunci : *Logam berat; rumput laut; lingkungan; perairan*

Introduction

A phenomenal environmental pollution comes from heavy metals. Heavy metal pollution is very worrying because it can cause health problems for humans and aquatic life. Sources of heavy metal pollution are generally from industrial, mining and household waste. Heavy metals that often cause pollution are lead (Pb), Mercury (Hg), Cadmium (Cd) and Chromium (Cr) (Hidayatullah et al., 2023; Farizky et al., 2022;

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Khandaker et al., 2021; Konda & Meiyasa., 2023; Ghoneim et al., 2014; Elhariri et al., 2020). Heavy metals are generally not easily decomposed and accumulate in animal and plant tissues. Therefore, effective, cheap, and environmentally friendly technology is needed as a solution to overcome this problem. The solution to overcome this problem is to utilize biological materials such as seaweed as metal absorbing agents (Elhariri et al., 2020; Komariyah et al., 2019; Ikhsan et al., 2023; Afiah et al., 2019).

Seaweed or often known as macroalgae is a marine organism whose habitat is in tropical and subtropical waters. Seaweed thrives in Indonesian waters so it can be used as food, cosmetics, medicines and fertilizers (Khandaker et al., 2021; Tampongangoy et al., 2021; Elhariri et al., 2020). Seaweed has bioactive compounds found in the cell walls in the form of carrageenan, alginate, fucoidan and some seaweeds can bind with metal ions (Ghoneim et al., 2014)(Sarangi et al., 2025). In addition, seaweed is rich in carboxyl, hydroxyl and sulfate groups which can absorb metals (Beup et al., 2024)(Konda & Meiyasa, 2023b). Therefore, seaweed has the potential as an absorbent material to overcome heavy metal pollution. This potential has been widely studied by several researchers but requires a comprehensive scientific review in the form of a review article.

The potential of seaweed as a metal absorbing agent is due to the fact that seaweed has a cell wall structure that contains hydroxyl, carboxyl and sulfate functional groups which are effective in binding metal ions. (Elhariri et al., 2020). The metal content in seaweed is a reflection of the pollution conditions in the environment where it grows so that seaweed can be used as a bioindicator of environmental quality. The process of analyzing metal content in seaweed helps in monitoring and assessing risks to the environment.

Seaweed that has been widely studied as a bioindicator of heavy metals such as *Eucheuma cottonii* (Munadi & Hamid, 2022; Tikat, 2021), *Kappaphycus alvarezii* (Tampongangoy et al., 2021) *Gracilaria* sp. (Harahap et al., 2019; Yulianto et al., 2018) *Sargassum* sp. (Suriadi, 2012) *Gracilariopsis heteroclada* (Beup et al., 2024), *Ulva Lactuca* (Ghoneim et al., 2014), *Caulerpa racemosa* (Farizky et al., 2022) dan *Codium fragile* (Hidayatullah & Tahir., 2023). The seaweed has the ability to accumulate metals in significant concentrations. Heavy metals that accumulate in the seaweed body not only affect the ecosystem but also humans. Therefore, it is important to know the levels of seaweed metals so as not to endanger human health. For the analysis of metal content in seaweed, it is generally carried out using the AAS (Atomic Absorption Spectroscopy) and ICP-MS (Inductively Coupled Plasma Mass Spectrometry) methods. However, the analysis method for detecting metal elements depends on the type of metal to be analyzed. Atomic Absorption Spectroscopy (AAS) is one of the metal analysis techniques commonly used in biological samples. The working principle of Atomic Absorption Spectroscopy (AAS) is by absorbing light by metal atoms in a free state. Atomic Absorption Spectroscopy (AAS) is able to measure metal levels in low concentrations so that it can detect metals in seaweed (Sarangi et al., 2025).

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Based on the literature that has been reviewed, seaweed has the potential as a bioindicator of metal pollution in aquatic environments. The analysis of metal content that has been carried out generally uses the AAS (Atomic Absorption Spectroscopy) method. Therefore, this literature review study was conducted to strengthen the urgency of further research on the potential of seaweed as a bioindicator agent of metal pollution in aquatic environments. The results of this study are expected to be a scientific basis for the development of metal analysis methods in the environment.

Heavy metal pollution in aquatic environments

The most serious environmental problem currently in the aquatic environment is heavy metal pollution (Syahputra et al., 2023). Heavy metals generally accumulate easily in the food chain and can even damage aquatic ecosystems. Heavy metals such as mercury (Hg), lead (Pb), cadmium (Cd), chromium (Cr) and arsenic (Ar) are examples of heavy metals that accumulate in water (Hidayatullah et al., 2023). According to the World Health Organization (WHO), heavy metals have no benefits but are very risky for health, such as nerve disorders, kidney disorders, and even cancer (Konda & Meiyasa, 2023b). Sources of pollutants such as industrial activities, mining, household and agricultural waste (Farizky et al., 2022).

The nature of heavy metals is difficult to degrade biologically and can persist for a long time in the environment. The metal settles at the bottom of the water and returns to the water when there is a change in the environmental conditions physically or chemically. This phenomenon causes heavy metals to remain in the water. Aquatic organisms such as fish, shellfish and seaweed can absorb metals from the water. The accumulation of heavy metals in aquatic organisms is known as bioaccumulation and biomagnification (Permanawati et al., 2013).

Heavy metals have a very diverse impact on human health depending on the type of metal and the level of exposure (Suryono & Indardjo, 2022). Various methods have been carried out for the analysis of heavy metals in water. The most common method is Atomic Absorption Spectroscopy (AAS). Various studies of heavy metal analysis in water have been carried out using AAS such as analyzing metals in water, sediment, and aquatic organisms (Kitong et al., 2012) (Tabel 1).

Tabel 1. Heavy metal levels in water

No	Heavy metal	Heavy metal levels	Water location	Description
1	Merkuri (Hg)	Upstream = 0.00052, Middle <0.005 and Downstream = 0.02145	River water in Pasie Raja District, South Aceh Regency	(Suryani et al., 2021)
2	Merkuri (Hg) and Arsen (As)	Hg = 0,00522 mg/l dan As = 0.00190 mg/l	Sea Water of Kao Bay, Dumdum Village, Kao Teluk District and Tabobo Village, Malifut District. North Halmahera Regency, North Maluku Province	(Thalib et al., 2023)

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3	Merkuri (Hg) and Arsen (As)	The amount of Hg in Lompad Village, Picuan Village, Karimbow I Village, Karimbow II Village and the Ranoyapo River estuary were respectively 0.05 ppm, 0.05 ppm, 1.3 ppm, 0.18 ppm and 0.05 ppm Total Hg in Lompad Village, Picuan Village, Karimbow I Village, Karimbow II Village and the Ranoyapo River estuary were respectively 3 ppm, 2 ppm, 100 ppm, 2 ppm and 1 ppm.	Sediment of the Lompad Village River, Picuan Village, Karimbow I Village, Karimbow II Village and the Ranoyapo River Estuary, Amurang District, North Sulawesi	(Kitong et al., 2012)
4	Cd, Cu, Cr and Pb	The Cd metal content ranges between 0.006 – 0.01 ppm, Cu between 0.0058 – 0.0720 ppm, Cr between 0.0170 - 0.0890 ppm and the Pb metal content ranges between 0.06 – 0.09 ppm	Bungus waters, Kabung Bay, Padang City	(Arifin et al., 2012)
5	Kadmium (Cd) and Kromium (Cr)	Still meets quality standards	Surface Water and Sediment of Saguling Reservoir, West Java	(Paramita et al., 2017)
6	Cu, Pb, Zn, Cd, and Cr	Pb = 26.020 ppm, Cu = 59.827 ppm, Zn = 167.240 ppm, Cd = 0.257 ppm, Cr = 78.405 ppm	Water and sediment in Jakarta Bay waters	(Permanawati et al., 2013)
7	Zn, Pb, Hg dan As	Zn ranges from <0.01 – 1.12 mg/l. Pb levels range from 0.09 – 0.14 mg/l. Hg levels $<3 \times 10^{-4}$. As levels range from $<2 \times 10^{-4}$ – 0.013 mg/l and have not exceeded the threshold of 5×10^{-2} mg/l	River Water, Tandano, North Sulawesi	(Maddusa et al., 2017)
8	Cr, Cu, Pb, Zn and Cd	Lead (Pb) 0.051 mg/l, Chromium (Cr) 0.062 mg/l, Copper (Cu)	West Flood Canal river water	(Ujianti & Androva, 2021)

	0.030, mg/l, Zinc (Zn) 0.053 mg/l, and Cadmium (Cd) 0.034 mg/l	

Table 1 shows that the content of heavy metals in waters exceeds the maximum threshold set by the government of Permen LHK No. P.68/2016, the safe limit for metal content in domestic wastewater is: Cd (0.05 mg/L), Cr (1.0 mg/L), As (0.05 mg/L), and Hg (0.002 mg/L). Heavy metals that exceed the threshold set by the government cause poisoning in aquatic organisms. Lead (Pb) and cadmium (Cd) can damage the nervous system and brain function of aquatic organisms. If the population of aquatic organisms decreases, it will disrupt the food chain and threaten the balance of the aquatic ecosystem. (Maddusa et al., 2017). The content of Hg and As metals in the sea water of Kao Bay, Dumdum Village, Kao Teluk District Hg = 0.00522 mg/l and As = 0.00190 mg/l (Thalib et al., 2023). The metal levels in the waters of Jakarta Bay are Pb = 26,020 ppm, Cu = 59,827 ppm, Zn = 167,240 ppm, Cd = 0.257 ppm, Cr = 78,405 ppm (Permanawati et al., 2013). Metal contamination of the West Flood Canal river water is Lead (Pb) 0.051 mg/l, Chromium (Cr) 0.062 mg/l, Copper (Cu) 0.030 mg/l, Zinc (Zn) 0.053 mg/l, and Cadmium (Cd) 0.034 mg/l (Ujianti & Androva, 2021).

Heavy metal pollution such as mercury (Hg) causes damage to the central nervous system, reproductive disorders, and behavioral changes. This is because mercury (Hg) can change mercury into methyl mercury (CH_3Hg^+) a toxic form that is easily absorbed by organisms (Thalib et al., 2023). Cd metal generally comes from battery waste, metal plating and phosphate fertilizers. Cr metal, especially Cr (VI) comes from the metal plating industry. Hexavalent chromium (Cr (VI)) is more dangerous than the trivalent form (Cr (III)). This is because Cr (VI) is carcinogenic and damages marine biota cell tissue (Paramita et al., 2017). As metal comes from mining and pesticides that flow into water bodies. Arsenic in inorganic forms such as arsenite (As III) and arsenate (As V) are more toxic than its organic form (Kitong et al., 2012).

Seaweed as a heavy metal absorbing agent

Seaweed is a marine organism that has the ability to absorb heavy metals in the aquatic environment through the absorption process (biosorption). This absorption process occurs due to the bonding of metal ions with functional groups found in the cell walls of seaweed. The ability of seaweed to absorb metal ions makes it a very potential bioremediation agent to overcome metal pollution in water. Several species of seaweed can absorb metals such as cadmium (Cd), lead (Pb), and mercury (Hg) (Znad et al., 2022). Seaweed can be a tempting offer in the industrial waste processing process because it is environmentally friendly and low cost.

Seaweed obtains or absorbs its food through the cells in its thallus. Nutrients carried by the water flow that hits the seaweed will be absorbed so that the seaweed can grow and reproduce. Seaweed can absorb heavy metals because of its ability as a biofilter. The availability of higher toxic metals in the waters will spur high absorption by seaweed. However, seaweed has a tolerance limit in dealing with water conditions that are polluted by toxic metals. Absorption of toxic metals in high concentrations and

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continuous conditions will cause the absorption capacity to decrease, which can result in plant death (Komariyah et al., 2019)

Several studies have conducted heavy metal absorption using seaweed, such as *Gracilaria verrucosa* (Chandra et al., 2018), *Caulerpa racemosa* (Farizky et al., 2022), *Ulva* sp (Novianti et al., 2020), *Codium fragile* (Hidayatullah et al., 2023), *Gracilaria edulis* (Preethi & Jeyanthi, 2023) and *Ulva reticulata* (Vijayaraghavan et al., 2005). Study conducted by(cKonda & Meiyasa, 2023) explained that *Kappaphycus alvarezii* seaweed can absorb heavy metals cadmium (Cd), lead (Pb), mercury (Hg), and copper (Cu) from the surrounding environment. In addition, some seaweed species are also able to accumulate heavy metals in higher concentrations. This shows that the potential of seaweed can be used as a bioindicator of heavy metals in waters. Seaweed can act as a bioindicator due to its ability to absorb dissolved substances directly from the environment including heavy metals such as Pb, Cd, Cu and Zn and nutrients such as nitrate and phosphate(Komariyah et al., 2019). Therefore, the chemical content of seaweed reflects the condition of the surrounding water environment.

However, seaweed raises concerns about human safety if consumed. Therefore, it is necessary to monitor the levels of heavy metals in seaweed.

Tabel 2. Comparison of heavy metal levels in various seaweed species

No	Types of seaweed	Heavy metal	Heavy metal levels in seaweed	Analysis method	Description
1	*Gracilaria* sp.	Cadmium (Cd)	The concentration of heavy metal cadmium (Cd) in seaweed Gracilaria sp. is 0.055 ppm	*Atomic Absorbtion Spectrofotometer* (AAS)	(Rokhmatin & Purnomo, 2022)
2	*Caulerpa racemosa*	Pb, Cd and As	Pb, Cd and As in the seaweed Caulerpa racemosa were respectively 0.0901 mg/kg, 0.0124 mg/kg and 0.2357 mg/kg.	*Atomic Absorbtion Spectrofotometer* (AAS)	(Farizky et al., 2022)
3	*Gracilaria sp*	Lead (Pb)	The levels of Pb metal in *Gracilaria* sp. m are 0.55 ppm, 1.77 ppm and 2.94 ppm	*Atomic Absorbtion Spectrofotometer* (AAS)	(Ihsan et al., 2015)
4	*Padina australis*	Lead (Pb)	The Pb metal content of Padina australis is 0.009 mg/kg, 0.002-0.015 mg/kg, 0.001 mg/kg.	*Atomic Absorbtion Spectrofotometer* (AAS)	(Saraswati & Rachmadiarti, 2021)
5	*Caulerpa taxifolia* and *Caulerpa racemosa*	iron (Zn) and copper (Cu)	The levels of heavy metals Zn and Cu in the seaweed Caulerpha taxophilia were 11.05 and 3,650 ppm. The	*Atomic Absorbtion Spectrofotometer* (AAS)	(Bhernama, 2024)

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			levels of heavy metals Zn and Cu in the seaweed Caulerpha recemosa were 18.46 and 12.26 ppm.		
6	*Sargassum Polycystum*	Lead (Pb) and Cadmium (Cd)	Pb and Cd metal levels in Sargassum Polycistum seaweed, are <0.0001 mg/Kg and 0.0004 mg/Kg	*Atomic Absorbtion Spectrofotometer* (AAS)	(Bhernama et al., 2021)
7	*Eucheuma cottonii*	Lead (Pb)	In Bluto waters, Pb content is 0.018ppm and 0.023ppm and in Saronggi waters, 0.256ppm and 0.0276ppm	*Atomic Absorbtion Spectrofotometer* (AAS)	(Rokhmatin & Purnomo, 2022)
8	*Ulva* sp	Zn, Pb, Cd and Cu	Zn = 4.63 - 21.33 mg/kg Pb = 2.61 - 16.00 mg/kg Cd = 1,93 – 5,56 mg/kg Cu = 3,80 – 3,86 mg/kg	*Atomic Absorbtion Spectrofotometer* (AAS)	(Elhariri et al., 2020)
9	*Enteromorpha* sp	Zn, Pb, Cd and Cu	Zn = 2.00 – 24.60 mg/kg Pb = 2.00 - 18.66 mg/kg Cd = 2.16 – 4.20 mg/kg Cu = 2.73 – 6.13 mg/kg	*Atomic Absorbtion Spectrofotometer* (AAS)	(Elhariri et al., 2020)
10	*Kappaphycus alvarezii*	Hg, Pb, Cd and Cu	Hg = 0.02 mg/kg, Cd = 0.9 – 1.46 mg/kg Pb and Cu were not detected	*Atomic Absorbtion Spectrofotometer* (AAS)	(Konda & Meiyasa, 2023b)
11	*Codium fragile*	Cu and Pb	Pb < 0,01 ppm and Cu 0,235 – 0,663 mg/L	*Atomic Absorbtion Spectrofotometer* (AAS)	(Hidayatullah et al., 2023)
12	*Eucheuma spinosum*	Cadmium (Cd)	Cd levels at 6 sampling points, namely A = 20.903 ppm, B = 29.770 ppm, C = 21.802 ppm, D = 14.964 ppm, E =16.187 ppm, F = 13.347 ppm.	*Atomic Absorbtion Spectrofotometer* (AAS)	(Rahmawati et al., 2020)
13	*Eucheuma cottonii*	Cadmium (Cd)	The levels of heavy metal cadmium in E.*cottonii* seaweed in Pamekasan waters, namely the content of heavy	*Atomic Absorbtion Spectrofotometer* (AAS)	(Setiabudi et al., 2014)

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			metal cadmium at station 1 was 0.0182 and at station 2 was 0.0262.		
14	*Gracilia* sp	Lead (Pb)	Location point 1, Pb concentration = 0.072 ppm (location A), 0.063 ppm (location B), 0.057 ppm (location D), 0.051 ppm (location E) and 0.046 ppm (location F). Location 2 Pb concentration = 0.096 ppm (location A), 0.083 ppm (location B), 0.071 ppm (location C), 0.065 ppm (location E) and 0.059 ppm (location F). For Location 3, Pb concentration = 0.142 ppm (location A), 0.108 ppm (location C), 0.097 ppm (location D), 0.084 ppm (location E) and 0.070 ppm (location F).	*Atomic Absorbtion Spectrofotometer* (AAS)	(Almahera et al., 2024)

The data in Table 2 shows that the heavy metals cadmium (Cd), lead (Pb), arsenic (As), mercury (Hg), copper (Cu) and zinc (Zn) were detected in various types of seaweed such as *Gracilaria* sp, *Caulerpa racemosa, Padina australis, Caulerpa taxifolia dan Caulerpa racemosa Sargassum Polycystum, Eucheuma cottonii, Ulva* sp*, Enteromorpha* sp*, Kappaphycus alvarezii, Codium fragile, Eucheuma spinosum. Gracilaria* sp, *Caulerpa racemosa* and *Eucheuma spinosum* has varying Cd levels, ranging from 0.0124 ppm to 29,770 ppm (Rokhmatin & Purnomo, 2022; Farizky et al., 2022; Bhernama, 2024; Rahmawati et al., 2020). The highest levels were found in Eucheuma spinosum at point B with a value of 29,770 ppm, this value exceeds the safe consumption threshold. This indicates that there are heavy metal pollutants at the location. Cd is a heavy metal that is dangerous and toxic and can accumulate in living tissue causing threats to human health and damage to aquatic ecosystems. (Farizky et al., 2022).

The highest levels were found in Eucheuma spinosum at point B with a value of 29,770 ppm, this value exceeds the safe consumption threshold. This indicates that there are heavy metal pollutants at the location. Cd is a heavy metal that is dangerous and toxic and can accumulate in living tissue causing threats to human health and

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damage to aquatic ecosystems (Ihsan et al., 2015). Although the Pb levels in various seaweed samples are relatively low, *Padina austral*is (0.009–0.015 mg/kg) (Saraswati & Rachmadiarti, 2021) but it remains a concern because Pb metal levels are dangerous if consumed. Pb metal when accumulated and consumed by humans will interfere with brain development, because of its neurotoxic nature. Heavy metal Pb comes from human activities originating from industrial waste, batteries and paint (Bhernama, 2024). The levels of Pb metal in Gracilaria sp seaweed vary from 0.046 – 2.94 ppm. This variation indicates that there are environmental and geographical factors that affect the level of Pb heavy metal contamination. The high and low values of heavy metal content are caused by the location of the pollution source, such as port areas or industrial areas (Hidayatullah et al., 2023).

Arsenic (As) is a heavy metal that is carcinogenic and causes chronic diseases when accumulated in the human body. Arsenic content can be absorbed by seaweed Caulerpa racemosa 0.2357 mg/kg (Farizky et al., 2022). Copper (Cu) and Zinc (Zn) in high levels are found in the seaweed species *Caulerpa taxifolia*, *Caulerpa racemosa*, *Ulva* sp., and *Enteromorpha* sp. The highest Zn reaches 24.60 mg/kg (Elhariri et al., 2020) and Cu up to 12.26 ppm (Bhernama, 2024) exceeding the threshold set by the government. Cu is a metal that is needed in the biological process of living things, but excess concentration of Cu can be toxic such as growth disorders, enzyme disorders, and cell death. The sources of Zn and Cu metals are generally from agricultural activities and electronic industry waste (Bhernama, 2024). In seaweed *Sargassum polycystum*, there is a low metal absorption rate, such as Pb < 0.0001 mg/kg and Cd only 0.0004 mg/kg (Bhernama et al., 2021). This shows that the habitat where this seaweed grows has a low level of heavy metal pollution.

Mercury (Hg) content was reported in the seaweed Kappaphycus alvarezii with a level of 0.02 mg/kg. Although the Hg level is low, it is dangerous to health because it is neurotoxic. Hg easily accumulates in organism tissue even at relatively low levels. The main source of Hg is generally from gold mining and chemical waste industry (Konda & Meiyasa, 2023b).

Differences in metal levels based on seaweed types and habitats indicate that geographic location is very important in spreading potential contamination and its risks. Therefore, location-based monitoring is very necessary for environmental management and safety of seaweed consumption. This is because each geographic location has different sources of pollution, seaweed types differ in their ability to absorb metals and environmental factors affect bioaccumulation (Hidayatullah et al., 2023).

A relatively clean environment can be used as a reference in the environmental management process. Conditions where variations in metal levels in seaweed indicate that some coastal areas are still free from heavy metal contamination and are still feasible in the seaweed cultivation process (Bhernama et al., 2021). However, regular monitoring is still carried out to ensure the sustainability of the ecosystem.

Conclusion

Seaweed has great potential as a bioaccumulator agent or absorber of heavy metals in aquatic environments. The cell structure and content of seaweed, especially polysaccharides (alginate, agar and carrageenan) are able to bind metal ions through the absorption process. Heavy metal content data from various types of seaweed show that species of *Ulva* sp., *Enteromorpha* sp., and *Eucheuma spinosum* are able to absorb Cd, Pb, Cu and Zn metals in significant amounts. Seaweed not only plays an important role in the food chain process, but also functions as a biological indicator and absorbent agent in the process of managing pollutant sources in waters.

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