Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(4): 1185 – 1197 (2025)
www.ejabf.journals.ekb.eg

Environmental Assessment of Water Quality and Its Impact on Nutrient Uptake and Mineral Absorption Capacity of *Gracilaria* and *Halymenia* Seaweeds in a Verticulture System in Teluk Kodek, North Lombok, NTB, Indonesia

Moh. Awaludin Adam[1], Salnida Yuniarti Lumbessy[2*], Dasep Hasbullah[1], Apri I. Supii[1], Petrus Rani Pong-Masak[3], Dahliatul Qosimah[4]

[1]Research Center for Marine and Land Bioindustry, National Research and Innovation Agency (BRIN), Mataram, Indonesia
[2]Aquaculture Study Program, Faculty of Agriculture, University of Mataram, Indonesia
[3]Research Center for Fisheries, National Research and Innovation Agency (BRIN), Cibinong, West Java, Indonesia
[4]Faculty of Veterinary Medicine, Brawijaya University, Malang, East Java, Indonesia

***Corresponding Author: salnidayuniarti@unram.ac.id**

ARTICLE INFO

Article History:
Received: March 24, 2025
Accepted: June 29, 2025
Online: July 19, 2025

Keywords:
Gracilaria,
Halymenia,
Teluk kodek,
Seaweed farming,
Vertical aquaculture systems

ABSTRACT

This study aimed to assess the water quality in Teluk Kodek, North Lombok, and analyze its influence on the nutrient absorption and mineral uptake capacities of *Gracilaria* and *Halymenia* seaweeds cultivated in a vertical aquaculture system. A descriptive research approach was employed, combining field surveys with laboratory analyses. Water quality was evaluated by measuring key parameters, including pH, dissolved oxygen (DO), temperature, salinity, and concentrations of ammonia, nitrate, nitrite, and heavy metals. Seaweed mineral absorption was assessed using X-ray fluorescence (XRF), and mineral characterization was conducted via Scanning Electron Microscopy (SEM) with EDX mapping. The results indicate that water quality in Teluk Kodek remains within a range suitable for seaweed cultivation; however, elevated ammonia and nitrate levels pose a potential risk of eutrophication. Nutrient and mineral uptake by *Gracilaria* and *Halymenia* was analyzed based on nitrogen, phosphorus, and heavy metal concentrations in the water. Both species demonstrated strong uptake capacities, with *Gracilaria* showing higher efficiency in absorbing nitrate and phosphorus. These findings provide valuable insights into the application of vertical aquaculture systems as a sustainable strategy for waste management and improving coastal water quality, supporting the advancement of environmentally responsible marine resource utilization.

INTRODUCTION

Teluk Kodek, located in North Lombok, NTB, is a coastal area with significant potential in both tourism and fisheries **(Junaidi *et al*., 2020)**. However, as human activities in the coastal zone have grown, the water quality in Teluk Kodek has been increasingly impacted by domestic waste, harbor waste, and other activities contributing to nutrient and heavy metal pollution **(Adam *et al*., 2024)**. These changes threaten the marine ecosystem, including species sensitive to water quality shifts **(Fromont *et al*., 2024; Trégarot *et al*., 2024)**.

Maintaining good water quality is essential for preserving the balance of aquatic ecosystems **(Bashir *et al*., 2020; Alam *et al*., 2024)**. Meanwhile, many water bodies face pollution threats, mainly due to excessive nutrients that lead to eutrophication **(Yang *et al*., 2008; Devlin & Brodie, 2023; Mazur *et al*., 2024)**. This process occurs when nutrients like nitrogen and phosphorus accumulate, causing a surge in algae growth and a deterioration of water quality **(Klimaszyk & Gołdyn, 2020; Xu *et al*., 2024)**. One approach to address water pollution is seaweed farming, particularly with species like *Gracilaria* and *Halymenia*, which effectively absorb nutrients (such as nitrogen and phosphorus) and heavy metals from the water **(Arumugam *et al*., 2018; Farghali *et al*., 2023; Ilac *et al*., 2024)**. Vertical aquaculture systems are ideal, as they enhance space efficiency and minimize environmental impact, particularly in waste management and improving water quality **(Yue & Shen, 2022; Mazur *et al*., 2024)**.

Red seaweeds, particularly *Gracilaria* and *Halymenia*, have significant potential for absorbing nutrients and minerals from the water **(Titlyanov *et al*., 2017; Theobald *et al*., 2024)**. These species help reduce water pollution and benefit aquaculture and food industries **(Arumugam *et al*., 2018; Farghl *et al*., 2021)**. However, studies examining the mineral absorption capacity of these species, particularly in vertical farming methods, are still limited **(Kim *et al*., 2024; Djoundi *et al*., 2025)**. Vertical farming, which involves cultivating seaweed in a vertical arrangement, offers advantages by improving nutrient and mineral absorption efficiency through enhanced water flow and ensuring uniform light distribution for photosynthesis **(Lomartire & Gonçalves, 2022; Khatimah *et al*., 2023)**.

Nevertheless, to ensure the success of seaweed farming in vertical systems, it is essential to assess the water quality in the area first **(Islam *et al*., 2022; Farghali *et al*., 2023)**. Parameters such as pH, temperature, dissolved oxygen (DO), salinity, and concentrations of ammonia, nitrate, nitrite, and heavy metals can affect the efficiency of nutrient absorption by seaweed **(Klimaszyk & Gołdyn, 2020; Kim *et al*., 2024)**. Therefore, this study aims to evaluate the water quality in Teluk Kodek and analyze its impact on the ability of *Gracilaria* and *Halymenia* to absorb nutrients and minerals, which in turn could serve as the basis for implementing an environmentally friendly vertical farming system. This research is expected to provide valuable information to support sustainable coastal management programs, enhance water quality, and promote the use of seaweed to support ecosystem sustainability and tourism in Teluk Kodek.

MATERIALS AND METHODS

This research was conducted from December 2024 to February 2025. The sampling of water, sediment, and seaweed, as shown in Fig. (1), was carried out in Teluk Kodek, Malaka Village, Pemenang District, North Lombok, NTB, Indonesia. The testing activities were conducted at the Marine Bioindustry Laboratory, the National Research and Innovation Agency (BRIN). The equipment used in this study included a plankton net, sample bottles, clip plastic, beakers, spatulas, measuring cylinders, analytical balances, freezers, microscopes, hot plates, ovens, cameras, aluminum foil, tweezers, pipettes, TDS meters, ammonia kits, phosphate kits, nitrate kits, nitrite kits, DO kits, markers, and Erlenmeyer flasks. The materials used included distilled water (aquades), filter paper, labels, tissues, water, sediment, and seaweed samples collected from the seas of Teluk Kodek. The test materials used were *Gracilaria* sp. and *Halymenia* sp. The research method was descriptive, using a field survey approach and laboratory test results.

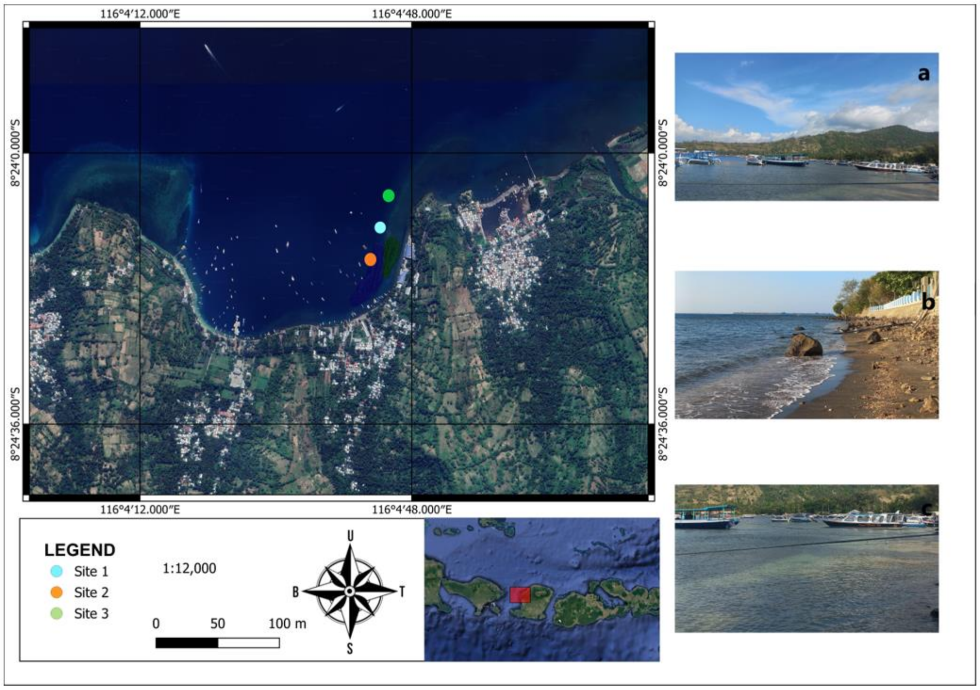


Fig. 1. Sample collection locations in Teluk Kodek; (a) Site 1: Existing longline location; (b) Site 2: Location near the boat dock; (c) Site 3: Existing floating cage location

1. Seaweed samples

The *Gracilaria* sp. and *Halymenia* samples shown in Fig. (2) were first washed with clean water to remove dirt and debris, then dried at a temperature of approximately 40–60°C. Following this initial drying process, the samples were placed in an oven for further drying until all moisture was fully removed. Once completely dried, a portion of the samples was stored for subsequent testing. The remaining samples were ground into a fine powder using a mortar and pestle, then sifted to produce *Gracilaria* sp. and *Halymenia* powder. These seaweed species were selected due to their strong nutrient absorption capabilities and their adaptability to a wide range of aquatic conditions.

(A) (B)

Fig. 2. Sample red algae collection locations in Teluk Kodek; (A) *Gracilaria*; (B) *Halymenia*

2. Water quality analysis

Water samples were collected from the waters of Teluk Kodek, Malaka Village, Pemenang District, North Lombok, NTB, Indonesia, at coordinates 8°30'–8°40' South Latitude and 116°07'–116°08' East Longitude. The sampling site corresponds to the planned location for implementing a vertical aquaculture system to cultivate *Gracilaria* and *Halymenia* seaweed. This study employed a triplicate sampling technique for both water and sediment samples. Water samples were analyzed for ammonia, phosphate, nitrate, nitrite, and dissolved oxygen (DO) using the Salifert Marine Test Kit. Additional parameters such as Total Dissolved Solids (TDS) and temperature were measured using a TDS meter, salinity using a refractometer, and heavy metals (Hg, Pb, and Cd) were analyzed via Atomic Absorption Spectroscopy (AAS).

3. Analysis of nutrient and mineral content in seaweed using x-ray fluorescence (XRF)

The *Gracilaria* sp. and *Halymenia* seaweed samples, processed into powder or flour, were analyzed for their absorbed mineral content using Energy Dispersive X-Ray Fluorescence (ED-XRF, Rigaku NexCG). Method modifications were based on suggestions from **(Sartika *et al*., 2024)**. The analysis was conducted at the Advanced Chemical Characterization II Laboratory, supported by the Electronic Science Service Application (ELSA) of the National Research and Innovation Agency (BRIN). Sample preparation involved placing powdered seaweed into specialized plastic holders for XRF analysis. Measurements were conducted by placing the sample on the instrument, launching the Manipal program, selecting the "Standardless Measure" menu, and entering the sample name in the "Sample ID" and "Measure" fields. After a few minutes, results appeared under the "Result" menu and were ready for printing.

4. Analysis of mineral characteristics in seaweed Uusng scanning electron microscopy (SEM)

The mineral characteristics of *Gracilaria* sp. and *Halymenia* samples were analyzed using Scanning Electron Microscopy (SEM), allowing for high-resolution observation of mineral structures and surface morphology. Proper sample preparation is crucial to preserving the sample's structural integrity for accurate SEM imaging. Oven-dried seaweed samples were characterized using a JEOL JSM-IT200 scanning electron microscope at the Advanced Physics Imaging Laboratory (ELSA, BRIN). The preparation stages followed established protocols, including sample orientation, fixation, dehydration, and application of a conductive coating. Modifications to this procedure were informed by **(Devos *et al*., 1998)**.

The fixation process involves two stages: the use of glutaraldehyde in a buffered solution, followed by osmium tetroxide in a buffer. Dehydration is conducted by immersing the sample in ethanol of increasing concentrations until reaching 100%. Critical Point Drying (CPD) is employed to avoid shrinkage, as described by **(Humphreys & Henk, 1979)**. Alternatively, hexamethyldisilazane (HMDS) can be used to eliminate remaining liquid without structural damage. A conductive gold coating is applied using a sputtering device. Variable Pressure Scanning Electron Microscopy (VP-SEM) mode was used to observe both prepared and unprepared biological and conductive samples.

5. Data analysis

Data were processed using Microsoft Excel 2023 and IBM SPSS Statistics 25. Variations in sampling locations and mineral absorption levels were analyzed using the standard error method, with a significance threshold of $P > 0.05$.

RESULTS

1. Water quality observation

During the research period, water quality remained stable within the range suitable for seaweed growth. Water quality parameters such as pH, temperature, dissolved oxygen, and salinity remained within optimal limits for the development of *Gracilaria* and *Halymenia* seaweeds. The results of the water quality measurements showed varying physical and chemical values for water and sediment samples, as presented in Table (1).

Table 1. Water quality parameters supporting red algae cultivation

Parameter	Measurement Results		Standard Quality
	Water sample	Sediment sampel	
	Physics		
pH	8.09±0.39	8.09±0.19	6-9
DO (mg/L)	6.60±0.28	5.8±0.28	>3.5
Temperature (^{O}C)	28.50±0.71	27.5±0.71	25-31
Salinity (ppt)	32.50±0.71	32±1.41	15-35
	Chemistry		
Ammonia (mg/L)	0.90±0.07	3.94±2.67	0.5 - 1.0
Nitrate (mg/L)	0.82±0.01	6.825±1.66	0.9-3.5
Nitrite (mg/L)	0.075±0.009	1.525±0.88	0.1 - 0.5
N total (mg/L)	17.50±0.71	0.335±0.09	0.5 - 5.0
C Organic (mg/L)	249.50±9.19	1.965±0.97	< 10
C Anorganic (mg/L)	72.0±1.41	0.365±0.06	-
C Total (mg/L)	321.5±10.61	2.595±0.66	> 50
C/N Ratio	18.37±0.14	7.77±0.17	8:1 - 15:1
	Heavy metal		
Pb (ppm)	0.003±0.0002	0.014±0.005	0.01
Cd (ppm)	0.0016±0.0003	0.011±0.002	0.01
Hg (ppm)	0.00012±0.0001	0.00022±0.0001	0.001

The pH values in both water and sediment samples were identical, at 8.09 ± 0.39, indicating slightly alkaline conditions. The Dissolved Oxygen (DO) content in the water sample (6.60 ± 0.28 mg/L) was slightly higher than in the sediment sample (5.80 ± 0.28 mg/L), reflecting better oxygenation in the water column. Water temperature and salinity were consistent between the two sample types, at approximately 28.5 °C and 32.5 ppm, indicating stable and uniform environmental conditions across the sampling site.

In terms of chemical composition, ammonia levels were significantly lower in the water sample (0.90 ± 0.07 mg/L) compared to the sediment sample (3.94 ± 2.67 mg/L), suggesting a higher degree of pollution in the sediment. Similarly, nitrate concentrations in the water (0.82 ± 0.01 mg/L) were lower than those in the sediment (6.83 ± 1.66 mg/L), indicating the potential for contamination sources or nutrient accumulation in the benthic layer. Nitrite concentrations followed the same trend, with higher values in the sediment (1.53 ± 0.88 mg/L) than in the water (0.075 ± 0.009 mg/L). The carbon-to-nitrogen (C/N) ratio was higher in the water sample (18.37 ± 0.14) compared to the sediment (7.77 ± 0.17), implying a greater degree of organic mineralization occurring in the sediment.

2. Nutrient and mineral absorption

The X-Ray Fluorescence (XRF) analysis revealed that both *Gracilaria* and *Halymenia* absorbed a variety of mineral elements. The detailed elemental concentrations absorbed by the seaweed samples are presented in Table (2).

Table 2. Element analysis results for the samples

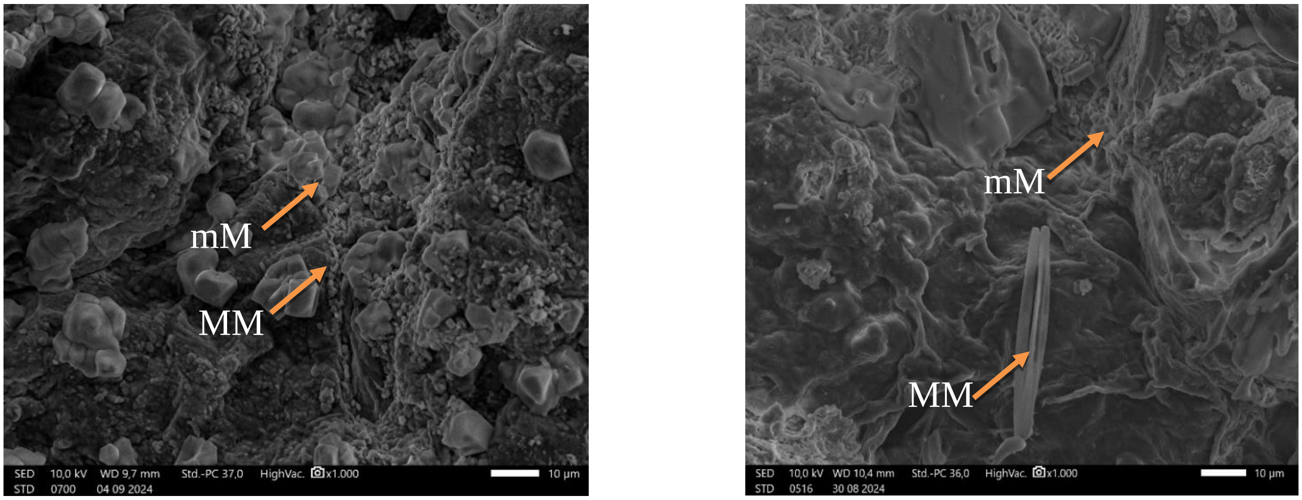
Elemental (% Massa)	Sample	
	Gracilaria	*Halymenia*
Br	0.40±0.01	0.30±0.03
Ca	5.70±0.02	6.20±0.1
Cl	22.90±0.04	23.20±0.02
Fe	0.50±0.11	0.20±0.03
K	25.70±0.01	24.10±0.11
Mg	0.50±0.02	0.70±0.01
Mn	0.20±0.05	0.15±0.02
P	1.30±0.01	1.20±0.02
S	11.10±0.25	12.20±0.21
Si	2.30±0.01	2.10±0.02
Sr	0.10±0.01	0.15±0.01

The X-Ray Fluorescence (XRF) analysis results show a comparative elemental composition between *Gracilaria* and *Halymenia*. Both seaweed species exhibit relatively similar elemental profiles, with some minor differences in concentrations. The dominant elements identified in both samples were potassium (K) and chlorine (Cl). *Gracilaria* contained 25.70% potassium and 22.90% chlorine, while *Halymenia* had 24.10% potassium and 23.20% chlorine.

In addition, *Gracilaria* contained 5.70% calcium (Ca) and 0.50% iron (Fe), whereas *Halymenia* showed slightly higher calcium content at 6.20% but lower iron at 0.20%. Other elements such as magnesium (Mg), manganese (Mn), phosphorus (P), sulfur (S), silicon (Si), and strontium (Sr) were also detected in both samples in comparable amounts. For instance, sulfur content was slightly higher in *Halymenia* (12.20%) than in *Gracilaria* (11.10%), and strontium was also marginally higher in *Halymenia* (0.15%) compared to *Gracilaria* (0.10%).

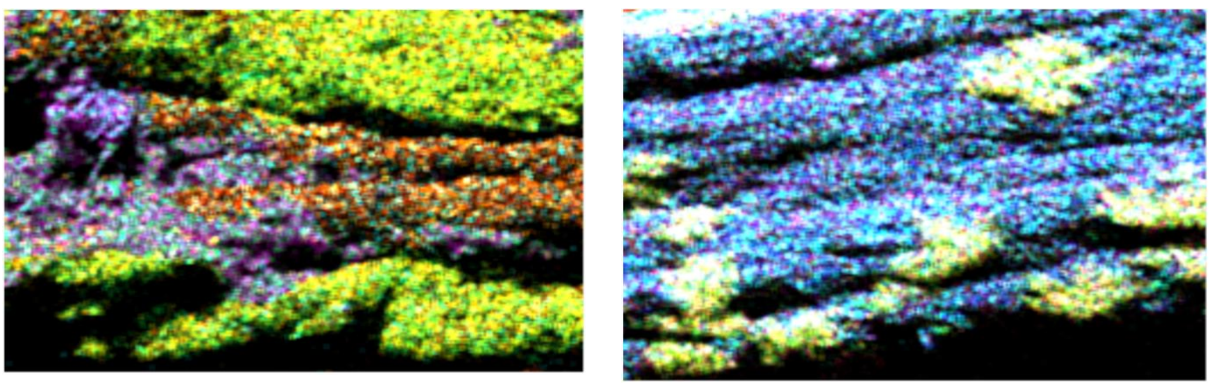
2. SEM observation

The Scanning Electron Microscopy (SEM) analysis revealed differences in the morphology and distribution of absorbed minerals between *Gracilaria* and *Halymenia*. As shown in Figs. (3, 4), the mineral absorption mapping highlights distinct surface structures and mineral deposition patterns for each species. These differences may reflect species-specific absorption capacities and microstructural adaptations for nutrient uptake.



(A) **(B)**

Fig. 3. Mineral absorption on the epidermis of red algae (A) *Gracilaria*; (B) *Halymenia*; (MM) Macro minerals; (mM) Micro minerals



(A) **(B)**

Fig. 4. Mineral absorption mapping on red algae (A) *Gracilaria* (B) *Halymenia*

The SEM analysis results indicate clear differences in the characteristics of mineral structures absorbed by *Gracilaria* and *Halymenia*, both at macro and micro scales. As illustrated in Fig. 2, which depicts mineral absorption on the algae epidermis, *Gracilaria* (A) and *Halymenia* (B) exhibit distinct absorption patterns. In both species, the absorbed minerals are categorized into macrominerals (MM) and microminerals (mM). In *Gracilaria*, macrominerals appear to be more evenly distributed across the epidermal surface, whereas microminerals tend to concentrate in specific localized areas. In contrast, *Halymenia* demonstrates a more heterogeneous mineral distribution, with macromineral absorption dominating in certain regions of the epidermis.

Further detail is shown in Fig. (3), which presents mineral absorption mapping. Both samples reveal differences in the intensity and spatial distribution of absorbed minerals. *Gracilaria* displays a more focused and organized mineral distribution pattern, while *Halymenia* exhibits a broader and more irregular spread. These distinctions highlight the differing capacities of the two red algae species to absorb and accumulate minerals, suggesting species-specific physiological or structural adaptations to mineral uptake at both macro and micro levels.

DISCUSSION

The research results indicate that the water quality in Teluk Kodek, the site used for cultivating the red algae *Gracilaria* and *Halymenia*, is relatively favorable and supports the growth of both species. The water exhibits a slightly alkaline pH (8.09 ± 0.39) and a relatively high dissolved oxygen (DO) level in the water sample (6.60 ± 0.28 mg/L), aligning with water quality standards for a healthy coastal ecosystem, as noted in previous studies **(Farghali *et al*., 2023; Ilac *et al*., 2024)**. However, concentrations of ammonia, nitrate, and nitrite are notably higher in sediment samples than in the water, indicating a greater pollution potential in the sediment—consistent with findings from **(Yue & Shen, 2022; Theobald *et al*., 2024)**.

The higher C/N ratio in the water sample (18.37 ± 0.14) compared to the sediment (7.77 ± 0.17) also reflects differences in the level of organic mineralization between the two media **(Farghali *et al*., 2023; Ilac *et al*., 2024)**. While heavy metal concentrations (Pb, Cd, Hg) are low in both sample types, slightly higher concentrations were detected in the sediment, indicating the potential for contaminant accumulation, similar to the results of **(Adam *et al*., 2018; Widiastuti *et al*., 2024)**. Overall, although the water quality in Teluk Kodek supports ecosystem sustainability and aquaculture potential, the contamination indicators in the sediment suggest a need for ongoing monitoring and management to prevent further degradation.

The mineral absorption analysis performed using X-Ray Fluorescence (XRF) demonstrated that both red algae species absorb similar mineral elements, with only minor differences. Both *Gracilaria* and *Halymenia* accumulated potassium (K) and chlorine (Cl) as dominant elements, which are essential for their growth. Minor differences were found in calcium, iron, sulfur, and strontium levels, possibly reflecting species-specific adaptations to local environmental conditions **(Kim *et al*., 2024; Djoundi *et al*., 2025)**. For instance, *Halymenia* exhibited a higher sulfur content, which may suggest a particular preference for this element in its aquatic environment **(Farghl *et al*., 2021; Theobald *et al*., 2024)**.

According to the XRF results, *Gracilaria* contained 25.70% potassium and 22.90% chlorine, while *Halymenia* had 24.10% potassium and 23.20% chlorine. Both species also showed comparable levels of calcium and iron, with slight differences in sulfur (higher in *Halymenia*) and strontium (slightly higher in *Halymenia*). These minor variations further underscore species-specific physiological traits that influence mineral uptake, consistent with previous findings **(Cai & Wang, 2019; Thodhal *et al*., 2019)**.

Additionally, SEM observations revealed differences in how the two species absorb and accumulate minerals at both macro and micro scales **(Hughes *et al*., 2021; Wu *et al*., 2023)**. *Gracilaria* exhibited a more uniform distribution of minerals across the epidermal surface, with micro-minerals localized in certain regions **(Yusup *et al*., 2020; Faruque *et al*., 2024)**. In contrast, *Halymenia* showed a more heterogeneous mineral distribution pattern, with macrominerals more heavily absorbed in specific epidermal areas **(Dehbi *et al*., 2023; Wu *et al*., 2023)**. These structural and functional differences highlight the distinct mineral absorption mechanisms of each species, which may influence their respective nutrient uptake efficiency and growth rates **(Adam *et al*., 2023; Sartika *et al*., 2024)**.

In conclusion, while the current water quality in Teluk Kodek is supportive of red algae cultivation, the findings emphasize the importance of continuous, sustainable management of both water and sediment quality. Particular attention should be given to controlling nitrogen compounds and mitigating heavy metal accumulation. Furthermore, the observed differences in mineral absorption between *Gracilaria* and *Halymenia* underscore the need for a deeper understanding of their physiological and ecological characteristics to enhance the efficiency of cultivation practices.

CONCLUSION

This research indicates that *Gracilaria* and *Halymenia* possess a notable ability to absorb nutrients and minerals from the waters of Teluk Kodek, North Lombok, functioning as natural biofilters. While the water quality is conducive to seaweed growth, the elevated nitrate and ammonia levels require further attention. XRF and SEM analyses revealed that both seaweed species effectively absorb heavy metals and minerals, which can contribute to reducing water pollution. This vertical farming method holds promise as a sustainable solution for improving water quality and restoring coastal ecosystems

AUTHOR CONTRIBUTIONS

Conceptualization: M.A.A. and D.H.; **Methodology:** S.Y.L., M.A.A., A.I.S., and P.R.P.M.; **Formal Analysis:** M.A.A. and D.Q.; **Resources:** M.A.A.; **Data Curation:** M.A.A., D.H., and D.Q.; **Writing—Original Draft Preparation:** M.A.A. and S.Y.L.; **Writing—Review and Editing:** M.A.A. and S.Y.L.; **Supervision:** A.I.S., D.H., P.R.P.M., and D.Q.; **Project Administration:** M.A.A.; **Funding Acquisition:** M.A.A.

FUNDING

The present study was financially supported funding from the National Research and Innovation Agency (BRIN) contract number 3/III.4/HK/2025 about the Research Team in the Purwarupa Programe for Aquatic Resource Utilization Innovation and Commercialization.

ACKNOWLEDGEMENT

The authors acknowledge the facilities, scientific and technical support from Lombok Marine and Land Bioindustry Laboratory, National Research and Innovation Agency.

REFERENCES

Adam, M. A.; Maftuch, M.; Kilawati, Y. and Tahirah, S. N. (2018). Analysis of heavy metal pollutant in Wangi River Pasuruan and its impact on Gambusia affinis. *Jurnal Pembangunan dan Alam Lestari*, 9(2), 120-

128. https://doi.org/10.21776/ub.jpal.2018.009.02.09

Adam, M. A.; Soegianto, A.; Risjani, Y.; Payus, C. M.; Yoga, R. G. P.; Sadi, N. H.; Susanti, E.; Khumaidi, A. and Ramli, R. (2023). The Cortisol Levels, Histology, and Fine Structure of Various Tissues of Fish Gambusia affinis (Baird and Girard, 1853) after Exposure to Lead. *Scientifica*, 2023, 1-12. https://doi.org/10.1155/2023/6649258

Adam, M. A.; Talbia, H.; Ariyanti, D.; Kristianto, S.; Chairunnisa, N. K.; Aprilia, M.; Firdaus, M.; Marzuki, R.; Iswara, A.; Prayogo, W.; Mutia, T. and Masruroh, H. (2024). Microplastics Contamination in Environment and Marine Animals at Kodek Bay, Lombok, Indonesia. *Water, Air, and Soil Pollution*, 235(789), 1-16. https://doi.org/10.1007/s11270-024-07607-2

Alam, M. M.; Jørgensen, N. O. G.; Bass, D.; Santi, M.; Nielsen, M.; Rahman, M. A.; Hasan, N. A.; Bablee, A. L.; Bashar, A.; Hossain, M. I.; Hansen, L. H. and Haque, M. M. (2024). Potential of integrated multitrophic aquaculture to make prawn farming sustainable in Bangladesh. *Frontiers in Sustainable Food Systems*, 8, 1412919. https://doi.org/10.3389/fsufs.2024.1412919

Arumugam, N.; Chelliapan, S.; Kamyab, H.; Thirugnana, S.; Othman, N. and Nasri, N. S. (2018). Treatment of Wastewater Using Seaweed: A Review. *International Journal of Environmental Research and Public Health*, 15(12), 2851. https://doi.org/10.3390/ijerph15122851

Bashir, I.; Lone, F. A.; Bhat, R. A.; Mir, S. A.; Dar, Z. A. and Dar, S. A. (2020). Concerns and Threats of Contamination on Aquatic Ecosystems. In *Bioremediation and Biotechnology: Sustainable Approaches to Pollution Degradation* (pp. 1-26). Springer. https://doi.org/10.1007/978-3-030-35691-0_1

Cai, C. and Wang, W. X. (2019). Inter-species difference of copper accumulation in three species of marine mussels: Implication for biomonitoring. *Science of The Total Environment*, 692, 1029-1036. https://doi.org/10.1016/j.scitotenv.2019.07.298

Dehbi, M.; Dehbi, F.; Kanjal, M. I.; Tahraoui, H.; Zamouche, M.; Amrane, A.; Assadi, A. A.; Hadadi, A. and Mouni, L. (2023). Analysis of Heavy Metal Contamination in Macroalgae from Surface Waters in Djelfa, Algeria. *Water*, 15(5), 974. https://doi.org/10.3390/w15050974

Devlin, M. and Brodie, J. (2023). Nutrients and Eutrophication. In A. Reichelt-Brushett (Ed.), *Marine Pollution – Monitoring, Management and Mitigation* (pp. 75-100). Springer. https://doi.org/10.1007/978-3-031-10127-4_4

Devos, E.; Devos, P. and Cornet, M. (1998). Effect of cadmium on the cytoskeleton and morphology of gill chloride cells in parr and smolt Atlantic salmon (Salmo salar). *Fish Physiology & Biochemistry*, 18(1), 15-27. https://doi.org/10.1023/A:1007782027346

Djoundi, A. R.; Morançais, M.; Mossion, A.; Ragueneau, E.; Rabesaotra, V.; Farasoa, H. R.; Ramanandraibe, V. V. and Dumay, J. (2025). Seasonal Variation in the Biochemical Composition and Fatty Acid Profiles of the Red Alga Halymenia durvillei from Ngazidja (Comoros). *Molecules*, 30(6), 1-28. https://doi.org/10.3390/molecules30061232

Farghali, M.; Mohamed, I. M. A.; Osman, A. I. and Rooney, D. W. (2023). Seaweed for climate mitigation, wastewater treatment, bioenergy, bioplastic, biochar, food, pharmaceuticals, and cosmetics: a review. *Environmental Chemistry Letters*, 21(1), 97-152. https://doi.org/10.1007/s10311-022-01520-y

Farghl, A. A. M.; Al-Hasawi, Z. M. and El-Sheekh, M. M. (2021). Assessment of Antioxidant Capacity and Phytochemical Composition of Brown and Red Seaweeds Sampled off Red Sea Coast. *Applied Sciences*, 11(23), 11079. https://doi.org/10.3390/app112311079

Faruque, M. O.; Uddin, S.; Hossain, M. M.; Hossain, S. M. Z.; Shafiquzzaman, M. and Razzak, S. A. (2024). A comprehensive review on microalgae-driven heavy metals removal from industrial wastewater using living and nonliving microalgae. *Journal of Hazardous Materials Advances*, 16, 100492. https://doi.org/10.1016/j.hazadv.2024.100492

Fromont, C.; Carrière, S. M.; Bédécarrats, F.; Razafindrakoto, M. and Roubaud, F. (2024). Long-term socio-environmental monitoring of protected areas is a persistent weak point in developing countries: Literature review and recommendations. *Biological Conservation*, 289, 110434. https://doi.org/10.1016/j.biocon.2023.110434

Hughes, A. H.; Magot, F.; Tawfike, A. F.; Rad-Menéndez, C.; Thomas, N.; Young, L. C.; Stucchi, L.; Carettoni, D.; Stanley, M. S.; Edrada-Ebel, R. and Duncan, K. R. (2021). Exploring the Chemical Space of Macro- and Micro-Algae Using Comparative Metabolomics. *Microorganisms*, 9(2), 311. https://doi.org/10.3390/microorganisms9020311

Humphreys, W. J. and Henk, W. G. (1979). Critical point drying of biological specimens. *Scanning Electron Microscopy*, 3, 235-240. https://doi.org/10.1111/j.1365-2818.1978.tb00106.x

Ilac, A. G.; Foronda, J. M. S.; Ayop, A. N.; Europa-Morales, A. L. and Ruadap, M. E. V. (2024). Exploring Growth of Gracilaria sp. using the Raft Culture Method. *Ilmu Kelautan: Indonesian Journal of Marine Sciences*, 29(4), 557-566. https://doi.org/10.14710/ik.ijms.29.4.557-566

Islam, M.; Sobuj, M. K.; Islam, R.; Hosain, M. and Rashid, M. (2022). Present Status of Seaweed Resources in Bangladesh: a Review on the Diversity, Culture Methods and Utilization. *Bangladesh Journal of Zoology*, 50(3), 283-307. http://dx.doi.org/10.3329/bjz.v50i3.65537

Junaidi, M.; Dwi, H. S. and Azhar, F. (2020). Demonstration Plot in Integrated Lobster and Pearl Shells Cultivation in the Context of Strengthening the North Lombok Community Partnership. *Agrokreatif: Jurnal Ilmiah Pengabdian Kepada Masyarakat*, 6(3), 249-259. https://doi.org/10.29244/agrokreatif.6.3.249-259

Khatimah, K.; Sompa, A. and Zaenab, S. (2023). The Potential of Seaweed Gracilaria sp. as An Organic Waste Bioremediation Agent. *International Journal of Applied Biology*, 7(1), 15-25. http://dx.doi.org/10.20956/ijab.v7i1.25336

Kim, S. T.; Conklin, S. D.; Redan, B. W. and Ho, K. K. H. Y. (2024). Determination of the Nutrient and Toxic Element Content of Wild-Collected and Cultivated Seaweeds from Hawai'i. *ACS Food Science & Technology*, 4(3), 595-605. https://doi.org/10.1021/acsfoodscitech.3c00476

Klimaszyk, P. and Gołdyn, R. (2020). Water Quality of Freshwater Ecosystems in a

Temperate Climate. *Water*, 12(9), 2643. https://doi.org/10.3390/w12092643

Lomartire, S. and Gonçalves, A. M. M. (2022). An Overview of Potential Seaweed-Derived Bioactive Compounds for Pharmaceutical Applications. *Marine Drugs*, 20(2), 141. https://doi.org/10.3390/md20020141

Mazur, R.; Kowalewski, Z.; Głowienka, E.; Santos, L. and Jakubiak, M. (2024). Sustainability in Aquatic Ecosystem Restoration: Combining Classical and Remote Sensing Methods for Effective Water Quality Management. *Sustainability*, 16(9), 3716. https://doi.org/10.3390/su16093716

Sartika; Adam, M. A. and Aryanti, D. (2024). Identification of Mineral Absorption in the Meat of Freshwater Kijing (Pilsbryoconcha exilis Lea) Using X-Ray Fluorescence (XRF). *Applied Research in Science and Technology*, 4(1), 1-12. https://areste.org/index.php/oai

Theobald, E. J.; Irving, A. D.; Capper, A.; Costa, J. F.; Diaz-Pulido, G.; Andrews, E. L.; Kelly, J. and Jackson, E. L. (2024). Selection of marine macroalgae for nutrient biofilter and bioproduct trials in the coastal waters of Queensland, Australia. *Aquaculture International*, 32(7), 9631-9669. https://doi.org/10.1007/s10499-024-01632-y

Thodhal, Y. S.; Raguraman, V.; Muniswamy, G.; Sathyamoorthy, G.; Rajan, R. R.; Chidambaram, J.; Rajendran, T.; Chandrasekaran, K. and Santha, R. R. (2019). Mineral and Trace Metal Concentrations in Seaweeds by Microwave-Assisted Digestion Method Followed by Quadrupole Inductively Coupled Plasma Mass Spectrometry. *Biological Trace Element Research*, 187(2), 579-585. https://doi.org/10.1007/s12011-018-1397-8

Titlyanov, E. A.; Titlyanova, T. V.; Li, X. and Huang, H. (2017). Common Marine Algae of Hainan Island (Guidebook). In *Marine Algae of Hainan Island* (pp. 75-228). Academic Press. https://doi.org/10.1016/B978-0-12-811963-1.00004-4

Trégarot, E.; D'Olivo, J. P.; Botelho, A. Z.; Cabrito, A.; Cardoso, G. O.; Casal, G.; Cornet, C. C.; Cragg, S. M.; Degia, A. K.; Fredriksen, S.; Furlan, E.; Heiss, G.; Kersting, D. K.; Maréchal, J. P.; Meesters, E.; O'Leary, B. C.; Pérez, G.; Seijo-Núñez, C.; Simide, R. and de Juan, S. (2024). Effects of climate change on marine coastal ecosystems – A review to guide research and management. *Biological Conservation*, 289, 110394. https://doi.org/10.1016/j.biocon.2023.110394

Widiastuti, I. M.; Adam, M. A. and Ernawati, E. (2024). Concentration and Distribution of Oligochaeta Worms in the Waters of Kejapanan, Pasuruan, Indonesia Polluted by Mercury Waste using DNA Barcode. *Jurnal Ilmiah Perikanan Dan Kelautan*, 16(2), 141-151. http://doi.org/10.20473/jipk.v16i2.56641

Wu, J. Y.; Tso, R.; Teo, H. S. and Haldar, S. (2023). The utility of algae as sources of high value nutritional ingredients, particularly for alternative/complementary proteins to improve human health. *Frontiers in Nutrition*, 10, 1277343. https://doi.org/10.3389/fnut.2023.1277343

Xu, Z.; Wang, Y.; Xie, L.; Shi, D.; He, J.; Chen, Y.; Feng, C.; Giesy, J. P.; Leung, K. M. Y. and Wu, F. (2024). Resilient water quality management: Insights from Japan's environmental quality standards for conserving aquatic life framework. *Environmental Science and Ecotechnology*, 22, 100472. https://doi.org/10.1016/j.ese.2024.100472

Yang, X.; Wu, X.; Hao, H. and He, Z. (2008). Mechanisms and assessment of water eutrophication. *Journal of Zhejiang University Science B*, 9(3), 197-209. https://doi.org/10.1631/jzus.B0710626

Yue, K. and Shen, Y. (2022). An overview of disruptive technologies for aquaculture. *Aquaculture and Fisheries*, 7(2), 111-120. https://doi.org/10.1016/j.aaf.2021.04.009

Yusup, D. S.; Mahardika, I. G.; Suarna, I. W. and Giri, I. N. A. (2020). Feeding preference and growth response of early adults abalone, Haliotis squamata on some macroalgae. *Biodiversitas*, 21(9), 4369-4375. https://doi.org/10.13057/biodiv/d210955

75. https://doi.org/10.13057/biodiv/d210956