How Effective is *Gracilaria* at Improving Water Quality? A Case Study in Indonesia

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Gracilaria is the third largest genus in the red algae group, comprising over 150 species globally. *Gracilaria* is famous for its agar production, a polysaccharide derived from the cell walls of the red seaweeds. It currently provides more than 50% of the world's supply of agar and plays a significant role in the production of agar. *Gracilaria* has also been shown to improve water quality in many parts of the world, such as China and the Philippines. To test whether *Gracilaria* might aid in water quality improvement in Indonesia, five variables (pH, ammonium (NH4; ppm), nitrite (NO2-; ppm), total alkalinity (ppm), and total hardness of water (ppm)) were analyzed in the presence and absence of *Gracilaria*. The results showed that the pH stayed constant throughout the 9-month experiment with its biggest increase being 15.3%, ammonium (NH4 (ppm)) had a decrease of 91.6%, nitrite (NO2- (ppm) levels fluctuated with percent changes ranging from an increase of 72.4% to 210.3%, the total alkalinity (ppm) dropped slightly with its lowest decrease being 22.2% but stayed constant throughout, and the total hardness (ppm) had minor changes with its lowest decrease being 14.3%. This study highlights the importance that *Gracilaria* may have in improving water quality, as these variables are present in nitrogen cycling. This study found that after *Gracilaria* is introduced into the system, ammonium decreases, potentially suggesting that the ammonium was oxidized. Ammonium oxidation is an important part of the nitrogen cycle and this is because it transforms ammonia, which can be harmful, into nitrate, which is easily used by plants. Further controlled studies are required to confirm this effect, but the results suggest that *Gracilaria* species may contribute to improved water quality in Indonesia.

Keywords: *Gracilaria*, Algae, pH, NH4, NO2-, Total Alkalinity, Total Hardness, Purify

Introduction

Algae aquaculture, also known as algaculture, is a form of aquaculture that involves the cultivation of algae. Algae are very effective in removing nutrients, particularly nitrogen and phosphorus, as well as harmful substances like heavy metals, pesticides, and both organic and inorganic toxins from water[1], and therefore can be used as a tool for the purification of water. The presence of algae can remove ammonium, phosphate, and nitrate and produce oxygen to allow the aerobic bacteria to break down any organic contaminants in the water5v. Because the presence of algae can naturally alter the quality of water, algae wastewater treatment is known to be an affordable and energy-conserving process. However, little is known about how species like *Gracilaria* affect water quality in low-tech, brackish aquaculture systems run by local communities, even though algae-based purification has been researched in controlled or industrial settings. By examining 9-month-long field data from a seaweed farm along the coast of Indonesia, this study seeks to close that knowledge gap and provide insights into the function of *Gracilaria* in realistic, community-based water treatment.

There are several different methods to treat water quality with algae. Some of the different water quality treatments are: "Algae-based heavy metal pollution treatment", "Algae-based wastewater treatment", and "Algae harvesting and bloom-forming cyanobacteria control"[2]. These technologies can treat any contaminants present, making algae an attractive method for water treatment. In 2022, Li et al. demonstrated that using algae to treat water is a cheaper and more energy-efficient method than traditional methods such as high-rate algal ponds, photo-bioreactors, algae-based membrane bioreactors, biofilm systems, microbial fuel cells, and immobilized systems[2].

Gracilaria is the third largest genus in the red algal group and can grow in a wide range of salinities, starting from 5 to 34 parts per thousand (ppt), giving it the ability to live in brackish water, the ocean, and mangrove swamps[3]. *Gracilaria* plays a significant role in producing agar[4]. Agar has a wide range of uses in the world. For example, agar can be used as a laxative, an appetite suppressant, a thickener in soups, fruit preserves, and many more[5]. *Gracilaria* has been shown to possibly improve water quality in Asia. *Gracilaria* can be found worldwide, with the majority of the species reported in subtropical and tropical waters[6]. Indonesia and China are currently the two main producing countries of *Gracilaria*[7]. *Gracilaria* species are relatively easy to cultivate compared to other seaweeds, as they adapt well to various environmental conditions beyond their natural

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habitat and are quite resilient[7]. Expanding upon *Gracilaria*'s function in possibly improving water quality, current research has investigated the ways in which algae-based systems can support sustainable aquaculture methods. "High rate algal pond treatment for water reuse in a marine fish recirculation system: Water purification and fish health" touches on the topic of a High Rate Algal Pond, also known as HRAP, which was used to treat an aquaculture system[8]. The study involved 3 rearing systems, and they all maintained a similar flow rate, temperature, pH, and salinity.

Sambung Asa is an algae farm and was founded on a single belief: empowering coastal communities in Indonesia through seaweed aquaculture, helping conserve freshwater resources in the local community. The collaboration between the facility and farmers enhances the local economy by offering farmers a consistent market and promoting a sense of partnership within the community[9]. Sambung Asa cultivates both Cottoni and *Gracilaria* to address environmental, economic, and social challenges directly while promoting the responsible use of marine resources. We partnered with Sambung Asa to conduct this study by analyzing their water quality data. Sambung Asa is interested in the effect *Gracilaria* has on the water it grows in, because seaweed cultivation does not require the use of fertilizers, and helps coastal communities with job opportunities. Growing *Gracilaria* also helps with climate change mitigation because out of every other flora on the land, seaweed absorbs and produces more CO2. Sambung Asa specifically chose seaweed because it has "simple and easy cultivation". .

Methods

This case study utilized two methodologies, discussed in detail below.

Data Collection

Sambung Asa collected water quality data from October 3, 2023, to June 6, 2024, to measure 5 parameters: pH, ammonium (NH4), nitrite (NO2-), total alkalinity (ppm), and total hardness (ppm). This study was not designed to be statistically analyzed, but rather to show general patterns in the presence of *Gracilaria*. In order to assess the potential effects of *Gracilaria* on nutrient levels, acidity, and mineral balance in the pond environment, these five parameters were chosen as indicators of water quality. The study took place over 246 days (October 3, 2023, to June 6, 2024), and water quality was measured eleven times in eighteen one-meter-deep seaweed cultivation ponds. There were no control ponds–that is, ponds absent of *Gracilaria*–available in this study. Although the entire farming area is 2.5 hectares, neither the average surface area nor the total volume of *Gracilaria* in each pond was recorded.

Depending on the weather, the seaweed was harvested after 40-45 days of growth and allowed to sun-dry for around two days. The seaweed needed longer drying times and was unable to completely dry outdoors. After the seaweed dried out and the samples were sent to a laboratory through mobile transportation for deeper analysis to discover whether or not *Gracilaria* helps in purifying the water, the last step Sambung Asa does is create agar-agar with it. Water samples were sent to the facility at each sampling date. Sampling was taken occasionally, approximately every two to three weeks, based on Sambung Asa's schedule. *Gracilaria* was introduced on October 8, 2023.

It is crucial to note that control groups of ponds without *Gracilaria* were not included in this research. One pre-cultivation baseline and several post-cultivation measurements are included in the water quality data, which helps in trend identification but prevents direct experimental comparison. Even though every attempt was made to guarantee consistency, there may be some variability in the data that Sambung Asa provided because of variations in sampling time, pond conditions that naturally fluctuate, or possible irregularities in laboratory measurements. This should be taken into account when analyzing the trends that were seen, particularly in variables that displayed a lot of fluctuations, like nitrite (NO2-).

Data Analysis

After receiving the dataset, the data was organized in Microsoft Excel and converted into a comma-separated value (CSV) file for easier analysis. The data was then imported to R Studio for the sole purpose of analyzing the data further and visualizing patterns in the data.

Because there was no control group, no statistical significance tests (like p-values or confidence intervals) were run. Using descriptive methods, the analysis focuses on tracking trends in five water quality parameters over a 9-month period. The exploratory nature of the data and the project's scope at the high school research level led to the selection of this methodology. Therefore, with the absence of a control group, this study calculates the percent change of each parameter in this research.

To understand how the 5 water quality parameters changed over the 9-month monitoring study, we calculated the percent change in each parameter throughout the study. The formula used to calculate the percent change is ((final-initial)/initial)*100. The percent change was calculated between the pre-*Gracilaria* datapoint and three different points of the experiment, the midpoint (February 13th, 2024) , the three-quarter point (April 25, 2024), and the endpoint (June 6, 2024).

Literature Review

The second part of this study was conducting a literature review. Researching and deeply understanding this complex topic would

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not have been possible without looking at many different articles and papers to acknowledge the complexity of this subject matter. This research studied more than ten research papers that were relevant to the theme of *Gracilaria* and water purification. The main search engine used to find appropriate research for this study was Google Scholar. Keyword-based searches were used to locate papers that were closely related to the research topic. The publication date filter was used to prioritize more recent data and only include sources from the 2010s onward in order to guarantee relevance and dependability. Finding books, peer-reviewed papers, scientific journals, and articles was the main goal of the search. The search was guided by keywords like "algae and purifying water" and the more focused "algae and purifying water in Indonesia".

Results

There were five variables in this data: pH, NH4 (ppm), NO2-(ppm), total alkalinity (ppm), and the total hardness (ppm) of the water. Five graphs were produced using R Studio, illustrating changes in water quality parameters. Such as the pH, NH4 (ppm), NO2-(ppm), total alkalinity (ppm), and total hardness (ppm) of the water.

Each figure shows trends in one measured water quality parameter. The x-axis contains the dates at which *Gracilaria* was cultivated (October 3, 2023, to June 6, 2024; 246 days total). The y-axis contains values of the measured variable.

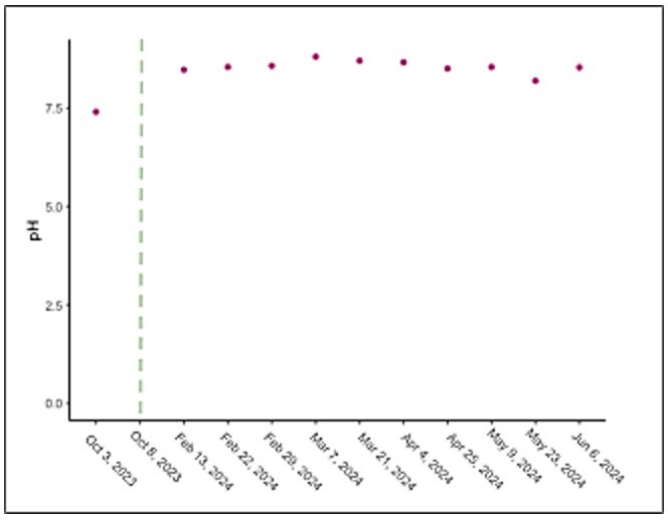

Fig. 1 pH levels of water throughout the year. The green dashed line on the graph is the date (October 8, 2023) when *Gracilaria* was added to the water.

Gracilaria was introduced on October 8, 2023. The pH level prior to its introduction was 7.4. The pH then steadily rose, reaching a high of 8.55 by the end of May 2024. After the introduction, the mean pH was 8.21 ± 0.4 (mean ± SD) up until June 6, 2024. Compared to the baseline, this indicates an increase of about 11%. Values steadied above 8.0 by February 13, 2024, and stayed in the 8.1 and 8.5 range until June 6, 2024, indicating a gradual increase (Table 1).

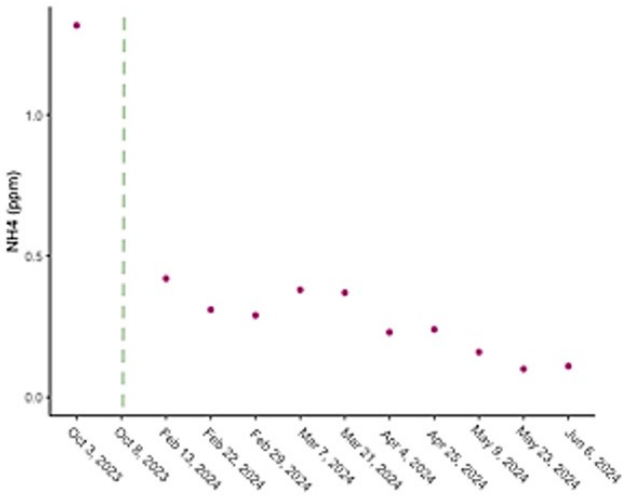

Fig. 2 NH4 levels (ppm) of the water throughout the year. The green dashed line on the graph is the date (October 8, 2023) when *Gracilaria* was added to the water.

The ammonium levels prior to *Gracilaria*'s introduction were 1.316 ppm. The levels rapidly decreased after the introduction of *Gracilaria*, reaching 0.29 ppm by February 13, 2024, before leveling off at a mean of 0.261 ± 0.113 ppm (mean ± SD) up until June 6, 2024. Compared to the baseline, there was a decrease of about 80% in ammonium concentration. After the big decrease from October 2023 to February 2024, the values stayed low and steady (Table 1).

The nitrite levels prior to *Gracilaria*'s introduction were 0.029 ppm. The levels of nitrite (NO2-) varied during the experiment. Compared to the baseline, the nitrite levels increased 186% to a peak of 0.083 ppm on February 13, 2024. NO2- levels leveled off at about 0.06 ppm between March 21, 2024, and April 25, 2024, before dropping once more on May 9, 2024. After the introduction of *Gracilaria*, the average nitrite concentration was 0.059 ± 0.0179 (mean ± SD) up until June 6, 2024 (Table 1).

The total alkalinity (ppm) level prior to *Gracilaria*'s introduction was 192 ppm. Compared to the baseline, there was a 15% decrease. Following the introduction of *Gracilaria*, the total alkalinity decreased to a mean of 163 ± 7.51 (mean ± SD) up until June 6, 2024 (Table 1).

The total hardness (ppm) of the water level prior to *Gracilaria*'s introduction was 3,483 ppm. After March 21, 2024, the levels gradually rose until they reached 3,195 ppm on June 6, 2024. Following the introduction of *Gracilaria*, the pH de-

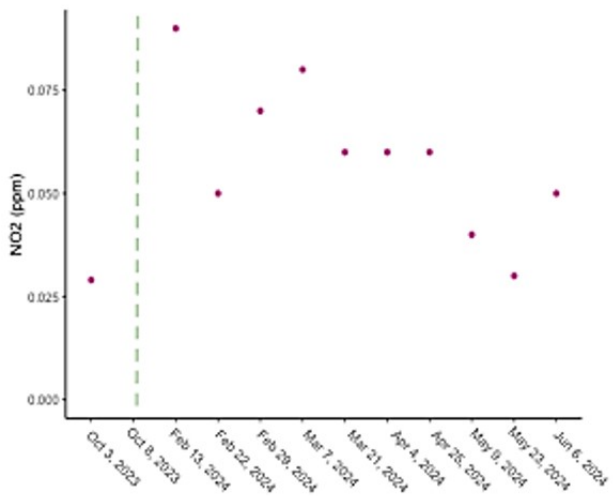

Fig. 3 NO2-(ppm) levels of the water throughout the year. The green dashed line on the graph is the date (October 8, 2023) when *Gracilaria* was added to the water.

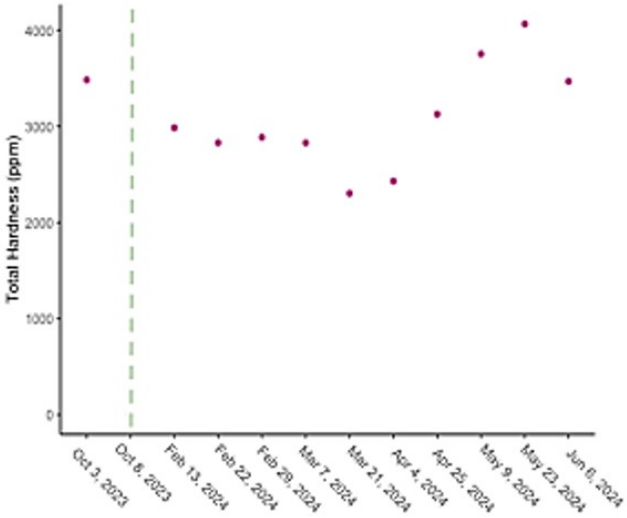

Fig. 5 Total hardness (ppm) of water throughout the year. The green dashed line on the graph is the date (October 8, 2023) when *Gracilaria* was added to the water.

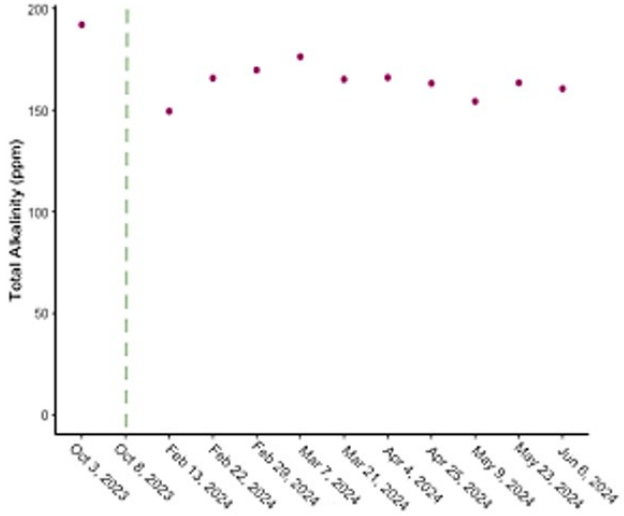

Fig. 4 Total alkalinity (ppm) of the water throughout the year. The green dashed line on the graph is the date (October 8, 2023) when *Gracilaria* was added to the water.

creased to a mean of 3,068 ± 555 (mean ± SD) up until June 6, 2024. Compared to the baseline, this resulted in a net decrease of 11.9% (Table 1).

Table 1. Percent change in water quality parameters through the experiment, October 3, 2023, to June 6, 2024. 1A depicts the percent change between pre-*Gracilaria* conditions (October 3, 2023) and the midpoint of data collection (February 13, 2024). 1B depicts the percent change between pre-*Gracilaria* conditions (October 3, 2023) and the ¾ points of data collection (April 25, 2024). 1C depicts the percent change between pre-*Gracilaria* conditions (October 3, 2023) and the endpoint of data collection (June 6, 2024).

Discussion

In coastal and agricultural settings, nutrient pollution and low water quality have become major issues for human and environmental health as the demand for clean water rises globally [10]. Natural remedies, like employing seaweeds to absorb excess nutrients, are becoming more popular as sustainable, low-cost ways to enhance the quality of water in ecosystems that are at risk [10]. This study found that there were notable improvements in water quality in brackish water pond systems when *Gracilaria* was present. The biggest shift was the 80% drop in ammonium (NH4+) levels, which was followed by a slight pH rise and a 15% drop in total alkalinity. Even though this shift in pH may appear minor, it is vital to remember that total alkalinity, which decreased early in the experiment, is a crucial pH buffer [11]. This implies that by affecting the water's buffering ability, *Gracilaria* might have indirectly helped to maintain a more stable and slightly higher pH. This study also concluded an 11.9% net drop in total hardness and nitrite (NO2-) levels varied but generally increased. These results imply that *Gracilaria* might improve nitrogen cycling and have quantifiable effects on water chemistry. It is crucial to remember that this study is observational and does not have a formal control group, even though these changes point to a connection between *Gracilaria*

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Table 1A			
Parameter	**pre-Gracilaria (October 3, 2023)**	**Midpoint (February 13, 2024)**	**Percent Change (%)**
pH	7.4	8.47	14.5
NH4	1.316	0.42	-68.1
NO2-	0.029	0.09	210.3
Total Alkalinity (ppm)	192	149.43	-22.2
Total Hardness (ppm)	3483	2985.29	-14.3
Table 1B			
Parameter	**pre-Gracilaria (October 3, 2023)**	**3/4 Point (April 25, 2024)**	**Percent Change (%)**
pH	7.4	8.50	14.9
NH4	1.316	0.24	-81.8
NO2-	0.029	0.06	106.9
Total Alkalinity (ppm)	192	163.14	-15.0
Total Hardness (ppm)	3483	3127.43	-10.2
Table 1C			
Parameter	**pre-Gracilaria (October 3, 2023)**	**Endpoint (June 6, 2024)**	**Percent Change (%)**
pH	7.4	8.53	15.3
NH4	1.316	0.11	-91.6
NO2-	0.029	0.05	72.4
Total Alkalinity (ppm)	192	160.57	-16.4
Total Hardness (ppm)	3483	3468.43	-0.4

cultivation and trends in water quality. Because of this, it is not possible to conclude that *Gracilaria* was the sole cause of these changes; rather, the findings present a correlation that might indicate a casual effect but does not prove it. These results point to the potential of using *Gracilaria* in sustainable water management; however, location-specific research is necessary to confirm its effectiveness, as it may differ depending on the environment.

In general, algae can improve water quality treatment by producing oxygen that allows aerobic bacteria to break down organic contaminants in the water and take up excess nitrogen and phosphorus in the process[12]. This study indicates that

Gracilaria does not have a significant effect on the pH of the water. We found that pH did not change as drastically as the other measured variables. On the other hand, NH4 (ppm) decreased dramatically. The lower the ammonium, the cleaner the water is from pollution. According to the National Standardization Agency 2015, quality parameters for *Gracilaria* include moisture content, impurities, clean anhydrous weed (CAW), yield, gel strength, viscosity, and heavy metal content [13,14]. The standard requires that the moisture content of *Gracilaria* seaweed does not exceed 12% while impurities should not be greater than 3% [14].

The nitrite (NO2-) levels showed significant variations in the levels. Given that nitrite is extremely sensitive to microbial activity, these fluctuations could be caused by a number of factors [15]. Variations in temperature, microbial activity, oxygen availability, and even *Gracilaria*'s impact on bacterial communities may be involved [15]. The dataset may also contain these fluctuations due to changes in lab sensitivity or environmental factors. These variables were not measured and are therefore still purely theoretical for the purposes of this research.

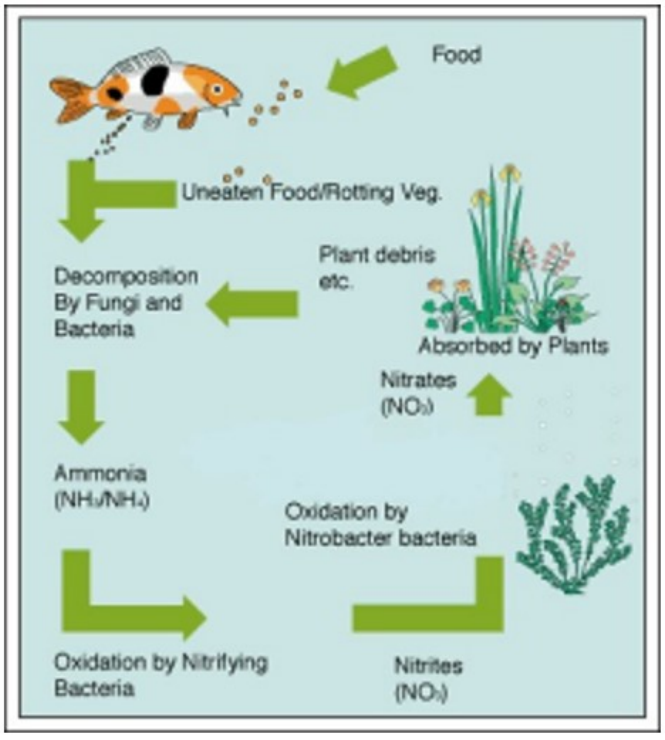

Fig. 6 Ammonium and Nitrogen Cycle. The figure was sent to me by Sambung Asa.

Apart from its physical characteristics, *Gracilaria*'s influence on water chemistry is closely linked to its function in the nitrogen cycle. The significant changes in water quality seen in this investigation may be explained by an understanding of the transformation of ammonium, nitrate, and nitrite. Figure 6 depicts the nitrogen cycle in relation to the processes taking place at the Sambung Asa facility (Figure 6). Natural organic matter and microbial decomposition are introduced by nitrifying bacteria to nitrite (NO2-) and subsequently to nitrate (NO3-). The ammonium is decomposed by the bacteria and fungi, and potentially oxidized by the nitrifying bacteria to make nitrate. The study's notable 80% drop in ammonium concentration points to potential active ammonium oxidation following the introduction of *Gracilaria*. The second phase of this process, where NO2- builds up before being transformed into nitrate, is consistent with the fluctuation and short increase in nitrite levels. The idea that *Gracilaria* enhances natural nitrogen processing, therefore indirectly improving water quality, is supported by microbial cycling. However, nitrate (NO3-) was not measured, and the corresponding nitrite (NO2-) data did not exhibit a consistent upward or downward trend. This study was unable to verify whether ammonium was oxidized to nitrite and subsequently nitrate without comprehensive nitrogen profiling. Consequently, the observed data do not offer direct mechanistic evidence, even though they are consistent with potential nitrogen cycling activity.

Total alkalinity refers to the capacity of the water to neutralize acids, thus, higher alkalinity indicates a higher buffering capacity. Alkaline substances in the water, such as hydroxides and carbonates, remove H+ ions, thereby reducing the water's acidity and increasing its pH level [16]. This experiment was held in fully brackish water, which tends to have a higher pH than freshwater because of its high salt content from the seawater. Additionally, brackish waters often contain high levels of dissolved organic matter, which significantly contributes to higher alkalinity [17]. According to the alkalinity results above, it dipped down initially but bounced back up and stayed at almost the same levels throughout the 246 days of the experiment. The initial decrease could be caused by a decomposition of fungi and bacteria that occurred rapidly at the start. The leveled results suggest that the system reached a period of stability where the production of bicarbonates from the decomposition balanced out consumption. Ultimately, the sources of dissolved organic matter and other nutrients determine whether the stabilization of results indicated improvement or degradation. The system is probably keeping the water quality high if the dissolved organic matter is normal and not too high. The total hardness of the water is the concentration of dissolved calcium and magnesium in the water. Hard water contains high levels of dissolved minerals, primarily calcium and magnesium [18]. Therefore, one of the reasons why the total hardness of water starts to rise (Figure 5), especially on April 25, 2024, is because there was an increase in the amount of dissolved minerals, primarily calcium and magnesium. *Gracilaria* can absorb minerals from seawater, resulting in a mineral content that is approximately 10-20 times higher than that of land plants [19]. As a result, the addition of *Gracilaria*

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may be beneficial for water quality. It is an important source of minerals with significant benefits for human nutrition[20].

Out of all of the results above, the parameter that changed the most is NH4. This is likely because the ammonium was decomposed by the fungi and bacteria from the water. NH4 in aquaculture increases stress on animals, like fish and shrimp[21]. When ammonium levels in water are high, aquatic organisms or animals struggle to effectively excrete the toxin, resulting in its accumulation in their tissues and blood, which can lead to death. Factors like pH and temperature can influence ammonium's toxicity to aquatic animals[22]. Under increased stress, shrimp and fish become more prone to diseases and exhibit lower feed conversion rates[21]. With lower feed conversion rates, there will be less uneaten food accumulated in the water which contributes to water pollution. The animals will also have less waste production. Less feeding leads to decreased excrement by the animals. Eutrophication is another possible effect of too many nutrients, especially nitrogen, and it can result in toxic algal blooms. These blooms can result in widespread marine life declines, lower oxygen levels, and prevent sunlight from reaching underwater plants. When the algae eventually die, they deplete the water oxygen supply[22]. According to the ammonium results above, there was a decline in ammonium levels. However, it stayed at that low level of ammonium throughout the whole experiment. The decline in ammonium levels is the result of nitrification, where the ammonium could have been converted into nitrite and subsequently nitrate, which reduces its concentration levels. Low and stable ammonium levels are an indicator of good water quality, suggesting effective nutrient cycling and a low risk of pollution.

Fig. 7 Algal blooms in a pond[20].

The appearance of an algal bloom in the absence of nitrogen management is depicted in Figure 7. Following the introduction of *Gracilaria*, ammonium (NH4+) concentrations in this study dropped by about 80%, indicating a significant nutrient uptake or conversion. This notable decrease in nitrogen suggests that *Gracilaria* cultivation may help prevent eutrophication by limiting excess nutrient buildup, even though algal blooms were not directly observed. This result is consistent with earlier research that demonstrated the potential of macroalgae such as *Gracilaria* as efficient bioremediation tools to lower nutrient pollution in coastal and aquaculture systems[23,24]. Using algae for water purification is not practiced in Indonesia alone. In the past decade, the large-scale cultivation of *Gracilaria* has grown quickly in the coastal waters in China. Since 2000, Nan'ao in Shantou City, Guangdong Province, has been successfully developed into one of the major industrial-scale cultivation bases for *Gracilaria* in South China[25]. It has been shown that cultivating *Gracilaria* offers environmental benefits, including mitigating eutrophication, controlling harmful algal blooms, maintaining healthy mariculture systems, and sequestering CO2. Its cultivation presents a new method for improving coastal environments in China and around the globe[25]. Integrating seaweeds into animal mariculture systems, known as mixed cultivation, has long been recognized as the most effective method for reducing pollution caused by aquaculture operations in the surrounding environment. Seaweed species such as Saccharina, Pyropia, Undaria, and *Gracilaria* are the species that are cultivated on an industrial scale in China[25].

Limitations

A potential limitation that occurred in this experiment was that there was only one data point to show how the water acted before *Gracilaria* was added. Assessing whether data on water quality were stable or varied significantly before *Gracilaria* was introduced was the aim. To increase the precision and dependability of the findings for subsequent studies, more data should be gathered prior to the introduction of *Gracilaria*. The absence of an official control group is one of the study's biggest limitations. It is impossible to draw firm conclusions that the seaweed was the only cause of the observed changes without simultaneous data on water quality from ponds without *Gracilaria*. To support the causal analysis of *Gracilaria*'s effects on water quality, future research should include side-by-side control and experimental groups, even though the baseline measurements provide some context.

The lack of statistical significance associated with no control groups is an additional limitation. Because there were no control groups and the study were exploratory in nature, no p-values or confidence intervals were computed, even though trends in variables like ammonium and nitrite were visually observed. Other factors like seasonal variations, microbial shifts, or external nutrient inputs cannot be ruled out in the absence of a control group. Therefore, rather than being direct effects of *Gracilaria*, the observed decrease in ammonium and other changes should be interpreted as correlations. The results of

this study are context-specific because it was only carried out at one aquaculture facility. Because environmental conditions in other regions may differ, it is important to exercise caution when making broader generalizations.

Another limitation of this study is that the analysis did not directly account for seasonal variability, such as variations in rainfall, temperature, or daylight duration. Future research should look into monitoring seasonal environmental data simultaneously with water quality monitoring, as these factors may have affected seaweed growth or drying times as well as water quality parameters. Furthermore, the study did not measure nitrate (NO3-), the end product of the nitrification process. This makes it more difficult for us to evaluate the entire nitrogen transformation route and ascertain whether ammonium was completely transformed into nitrate. The dataset only contains one water quality measurement made prior to the introduction of *Gracilaria*, which is another limitation. Because of this, it is challenging to say whether the changes that were seen were caused by *Gracilaria* cultivation or were a result of a natural trend. Multiple pre-intervention data points would be necessary for a more trustworthy baseline in order to account for the system's inherent variability. Additionally, the application of formal statistical tests was restricted by the observational nature of the dataset and the variability in sampling frequency. As a result, descriptive evaluation of trends was used instead of hypothesis testing.

Conclusion

This study concludes that *Gracilaria may contribute to the improvement of the water quality* of brackish water in Indonesia. These results show that the methods used to conduct this experiment were effective in concluding that *Gracilaria* potentially improves the quality of water. This case study is specifically in Indonesia.China and the Philippines are some of the biggest cultivators of *Gracilaria and are in the same region as Indonesia*. In the Philippines, there was a study that investigated the impact of short-term Nitrogen enrichment on the growth and agar quality of Gracilariopsis heteroclada. Sambung Asa did this by soaking the planting materials in varying concentrations of ammonium chloride (NH4Cl) for 6 hours, and the finding suggests that short-term Nitrogen enrichment could be a viable culture strategy to boost Gp. heteroclada production and reduce farming costs[26]. In China, a large-scale cultivation of the seaweed *Gracilaria* has rapidly expanded along China's coastal waters. *Gracilaria* production has increased from 50,536 tons in 2003 to 114,722 tons in 2010. Since 2000, Nan'ao in Shantou City, Guangdong Province, has emerged as a major industrial-scale cultivation base for *Gracilaria* lemaneiformis in South China[25]. *Gracilaria* cultivation can significantly help remediate contaminants in mariculture ecosystems, enhance water quality, and offer a promising method for improving coastal environments in China and globally[25].

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