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Analysis of Growth Efficiency and Daily Growth Rate of Seaweed (G. verrucosa, G. lichenoides, and G. gigas) at Various Salinity Levels Based on the Final Weight-to-Initial Weight Ratio

Dewi Virgiastuti Jarir[1,3*], Fina Fatwasari[1], Toto Hardianto[2], Nurayu Pratiwi[3], Anton[2]
[1]Fisheries Science Study Program, Faculty of Science and Technology, Cahaya Prima University, Indonesia
[2]Department of Fisheries Science, Faculty of Agriculture and Fisheries, University of Dumoga Kotamobagu, Indonesia
[3]Department of Aquaculture, Bone Marine and Fisheries Polytechnic, Indonesia

ABSTRACT

This study investigated the effects of salinity variation on the growth efficiency and daily growth rates of three commercially important seaweed species: *Gracilaria verrucosa*, *G. lichenoides*, and *G. gigas*. The experimental design tested five salinity levels (10, 15, 20, 25, and 30 ppt) under controlled conditions during an 8-week cultivation period. Growth parameters were measured weekly, and data were analyzed using the Kruskal-Wallis non-parametric test. Results from the Kruskal-Wallis test revealed no significant effect of either salinity variation or seaweed species on growth efficiency and daily growth rate ($p>0.05$). Although observable differences in mean ranks occurred, these variations were not statistically significant. These findings conclude that all three *Gracilaria* species exhibit similar growth patterns across various salinity levels, demonstrating their adaptability to salinity changes without significant impacts on growth efficiency and daily growth rate. Further research should investigate other environmental factors such as nutrient availability, light intensity, and temperature to optimize cultivation conditions

KEY WORDS: *Gracilaria*, salinity, growth efficiency, daily growth rate, environmental adaptation, seaweed cultivation

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Corresponding Author:
Dewi Virgiastuti Jarir

1. INTRODUCTION

Seaweed, especially Gracilaria, is an important commodity in the fisheries industry, both ecologically and economically. Gracilaria verrucosa, Gracilaria lichenoides, and Gracilaria gigas are widely cultivated in Indonesia's coastal areas due to their ability to adapt to salinity variations. As the main raw material for agar production, Gracilaria has high market demand, particularly in the food and pharmaceutical industries (Diatin et al., 2020).

Gracilaria cultivation in Indonesia is often carried out in ponds that are also used for polyculture activities, such as with milkfish (Chanos chanos) and tiger prawns (Penaeus monodon). This polyculture system enhances productivity and economic efficiency, benefiting small-scale coastal farmers (Rimmer et al., 2021). Additionally, seaweed cultivation not only improves the economic well-being of communities but also contributes to ecological balance by enhancing water quality and absorbing excess nutrients such as nitrogen and phosphorus (Abreu et al., 2011).

One of the main challenges in Gracilaria cultivation is maintaining optimal salinity levels for growth and agar production. Studies show that a salinity range of 20–25 ppt is ideal for daily growth and maximum agar content, reaching up to 40.71% (Anton, 2017). This makes Gracilaria highly suitable for cultivation in Indonesia's diverse coastal waters with varying salinity levels.

This research aims to analyze the growth efficiency and daily growth rate of three seaweed species: Gracilaria verrucosa, Gracilaria lichenoides, and Gracilaria gigas, across different salinity levels. Growth efficiency will be measured based on the final weight-to-initial weight ratio, while the daily growth rate will be calculated to track growth changes per day at different salinity levels. Previous studies have shown that environmental factors such as salinity can affect seaweed growth and agar content. In this context, Gracilaria has demonstrated optimal growth potential within certain salinity ranges, such as Gracilaria verrucosa and Gracilaria lichenoides, which show the best growth rates at 20–25‰, with G. verrucosa reaching a daily growth rate of 4.95% at 25‰ salinity (Choi et al., 2006).

Although the effects of salinity on growth and agar content have been studied extensively, the analysis of growth efficiency based on the final-to-initial weight ratio and daily growth rate across different salinity levels has not been thoroughly explored. Therefore, this study aims to fill this gap, providing a deeper understanding of how salinity treatments influence seaweed production efficiency and growth rate in a fisheries cultivation context

2. MATERIALS AND METHODS

This study employs a field experiment method involving different salinity levels and three seaweed species: *Gracilaria verrucosa*, *Gracilaria lichenoides*, and *Gracilaria gigas*. The research aims to analyze growth efficiency based on the final weight-to-initial weight ratio for each treatment. The experimental design uses a completely randomized design with five different salinity levels: 10 ppt, 15 ppt, 20 ppt, 25 ppt, and 30 ppt. Each salinity treatment is applied to all three seaweed species, with each combination repeated three times, resulting in 45 experimental units.

The population in this study includes all available *Gracilaria* species for cultivation in coastal waters, focusing on three widely cultivated species: *G. verrucosa*, *G. lichenoides*, and *G. gigas*. The research samples are seaweeds cultivated in controlled aquatic environments for each salinity treatment. Each container is filled with 100 grams of initial seaweed weight, and observations are conducted over 8 weeks.

Data collection involves measuring seaweed weight weekly for each treatment. The final seaweed weight is measured at week 8, and the daily growth rate is calculated based on the weekly weight. Daily weight increments are recorded to identify growth patterns over time. Instruments used include a digital scale with 0.01-gram accuracy for measuring seaweed weight and a salinity meter to ensure that water conditions are consistent with the treatment.

Data analysis is performed by evaluating the growth efficiency of seaweed based on the final-to-initial weight ratio, as well as the daily growth rate and differences between treatments using the Kruskal-Wallis test.

The Growth Efficiency Ratio is calculated using the following equation:

$$\text{Growth Efficiency Ratio} = \frac{\text{Final Weight}}{\text{Initial Weight}}$$

where "Final Weight" represents the seaweed's weight at the end of the observation (week 8), and "Initial Weight" is the seaweed's weight at the beginning of the study, set at 100 grams in this study. This ratio indicates how efficiently seaweed grows under specific treatment conditions. The growth efficiency ratio has been used in various studies to assess growth response under different environmental conditions, as in the study by Al-Hafedh et al. (2015), which found that the daily growth ratio of Ulva lactuca can be influenced by stocking density and water flow rate.

Next, the Daily Growth Rate (G) is calculated to track changes in seaweed growth per day throughout the study period. The equation used is:

$$G = \left(\left(\frac{W_t}{W_0} \right)^{\frac{1}{t}} - 1 \right) \times 100\backslash\%$$

where W_t is the seaweed's weight at time t (week -n), W_0 is the initial seaweed weight (100 grams), and t is the observation time in days. This daily growth rate provides an overview of seaweed growth per day and identifies treatments that yield the highest growth rate. This formula has been used in previous studies by Peng et al. (2022) to evaluate the daily growth rate of *Gracilaria tenuistipitata* at different densities in polyculture systems.

To test for significant differences between treatments, the Kruskal-Wallis test is used. This test aims to evaluate the effect of salinity levels and seaweed species on the Growth Efficiency Ratio and Daily Growth Rate. The Kruskal-Wallis test model used is as follows:

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} - 3(N+1)$$

In this model:

- **H** is the Kruskal-Wallis test statistic.
- **N** is the total sample size.
- **k** is the number of groups (number of salinity levels and seaweed species).

- R_i is the sum of ranks in group *i*.
- n_i is the sample size in group *i*.

This test examines the null hypothesis that the medians of all groups are the same. If the *H* value indicates a significant difference, the null hypothesis is rejected, and post-hoc tests such as Dunn's Test can be performed to determine which groups differ significantly in seaweed growth

3. RESULTS

The results show that salinity variation does not significantly affect the growth efficiency ratio and daily growth rate of the three seaweed species tested: *Gracilaria verrucosa*, *Gracilaria lichenoides*, and *Gracilaria gigas*. These findings were obtained through the Kruskal-Wallis test, used to evaluate differences in median values across salinity treatments and seaweed species groups. Based on the analysis, the Asymp. Sig. value was greater than 0.05 in all tests conducted, indicating no significant difference in either the growth efficiency ratio or daily growth rate. The results of the analysis are presented in Table 1.

Table 1. Analysis of the Growth Efficiency Ratio by Salinity and Seaweed Species

Variable	Treatment Group	Mean Rank	H	df	Asymp. Sig.
Salinity Level	10 ppt	10.67	5.433	4	0.246
	15 ppt	7.00			
	20 ppt	4.00			
	25 ppt	7.00			
	30 ppt	11.33			
Seaweed Species	*G. verrucosa*	6.40	0.960	2	0.619
	G. lichenoides	8.80			
	G. gigas	8.80			

Mean Rank = mean rank in non-parametric test, H = Kruskal-Wallis statistic, df = degrees of freedom, Asymp. Sig. = asymptotic significance (2-tailed).

In detail, for the growth efficiency ratio based on salinity levels, the Asymp. Sig. value obtained was 0.246, with an H value of 5.433 and a degree of freedom (df) of 4. This indicates that there is no significant difference between the treatment groups of 10 ppt, 15 ppt, 20 ppt, 25 ppt, and 30 ppt salinity levels in relation to the growth efficiency ratio of seaweed. The highest mean rank for the efficiency ratio was found at 30 ppt salinity, with a mean rank of 11.33, while the lowest mean rank was at 20 ppt salinity, with a mean rank of 4.00. These visual differences suggest small variations in growth efficiency, but they are not statistically significant enough to indicate any real impact of salinity variation.

Meanwhile, for the growth efficiency ratio based on seaweed species, the Kruskal-Wallis test results showed an Asymp. Sig. value of 0.619, with an H value of 0.960 and 2 degrees of freedom. The highest mean rank in this test was found for *G. lichenoides* and *G. gigas*, both with a mean rank of 8.80, while the lowest mean rank was for *G. verrucosa*, with a mean rank of 6.40. Although numerical differences exist between seaweed species, the analysis results indicate that these differences are not significant, meaning that all three *Gracilaria* species exhibit similar growth efficiency patterns across different salinity treatments.

The daily growth rate analysis showed similar results. For daily growth rate based on salinity levels, the Asymp. Sig. value obtained was 0.472, with an H value of 1.500 and 2 degrees of freedom. The highest mean rank was found at 20 ppt salinity, with a mean rank of 11.33, while the lowest mean rank was at 30 ppt salinity, with a mean rank of 4.67 (Table 2). Although there were variations in growth rates between salinity levels, the results indicate that salinity treatments did not significantly affect the daily growth rate of *Gracilaria*.

Similarly, comparisons among seaweed species yielded identical statistical results (*H* = 1.500, *df* = 2, *Asymp. Sig.* = 0.472, Table 2), with *G. verrucosa* having the highest mean rank (10.00) and both *G. lichenoides* and *G. gigas* sharing the lowest (7.00) (Table 2).

Table 2. Analysis of Daily Growth Rate by Salinity and Seaweed Species

Variable	Treatment Group	Mean Rank	H	df	Asymp. Sig.
Salinity Level	10 ppt	5.33	1.500	2	0.472
	15 ppt	8.67			
	20 ppt	11.33			
	25 ppt	10.00			
	30 ppt	4.67			
Seaweed Species	*G. verrucosa*	10.00	1.500	2	0.472
	G. lichenoides	7.00			
	G. gigas	7.00			

Mean Rank = mean rank in non-parametric test, H = Kruskal-Wallis statistic, df = degrees of freedom, Asymp. Sig. = asymptotic significance (2-tailed).

For the daily growth rate based on seaweed species, the Asymp. Sig. value obtained was 0.472, with an H value of 1.500 and 2 degrees of freedom. The highest mean rank was found in *G. verrucosa*, with a mean rank of 10.00, while the lowest mean rank was found in *G. lichenoides* and *G. gigas*, both with a mean rank of 7.00. The absence of significant differences between seaweed species indicates that all three species had similar daily growth rate responses across the tested salinity variations

4. DISCUSSION

These findings are consistent with previous research, which showed that Gracilaria has good tolerance to salinity variations, and changes in salinity across a wide range do not significantly affect growth efficiency or daily growth rate. Research by Alves et al. (2021) demonstrated that Gracilaria birdiae grows well within a salinity range of 20 to 50 ppt, while growth is significantly hindered at extreme salinities (0 and 60 ppt). This confirms that Gracilaria is a euryhaline species, tolerant of significant salinity changes as long as they do not exceed its specific tolerance limits.

Additionally, Raikar et al. (2001) found that most Gracilaria species, including Gracilaria vermiculophylla and Gracilaria arcuata, achieve optimal growth rates in normal seawater salinity (35‰) and adapt well to salinity ranges between 15‰ and 30‰. This suggests that salinity variation within reasonable ranges in cultivation environments is not always the main limiting factor in Gracilaria growth.

In the context of seaweed growth theory, these results support the understanding that other factors, such as nutrient availability, light intensity, and interactions with other organisms, also play important roles in Gracilaria growth. A study by Wu et al. (2018) further supports these findings, showing that salinity variation influences nutrient absorption and growth in Gracilaria vermiculophylla, but interactions with other environmental factors, such as nutrient availability, are more critical in determining overall growth success.

Based on the results of the Kruskal-Wallis test analysis, it can be concluded that variations in salinity and seaweed species did not have a significant effect on the growth efficiency ratio and daily growth rate of the three seaweed species tested, namely Gracilaria verrucosa, Gracilaria lichenoides, and Gracilaria gigas.

Although visual differences in mean ranks were observed across salinity levels and seaweed species, these differences were not statistically significant. This indicates that the three Gracilaria species exhibit relatively similar growth patterns across the different salinity levels tested, demonstrating that Gracilaria can adapt well to salinity variations without significantly affecting growth efficiency or daily growth rate.

Although this study did not find significant effects of salinity variations on daily growth rate, further research is recommended. Future studies should take into account other environmental factors such as nutrient availability, light intensity, and temperature to gain a more comprehensive understanding of Gracilaria growth in cultivation environments.

5. CONCLUSION

This study demonstrated that variations in salinity levels ranging from 10 to 30 ppt did not significantly affect the growth efficiency ratio or daily growth rate of *Gracilaria verrucosa*, *Gracilaria lichenoides*, and *Gracilaria gigas*. The Kruskal–Wallis test indicated that all three seaweed species showed relatively similar growth responses under different salinity treatments, confirming their high adaptability to varying environmental conditions. These findings highlight the potential of *Gracilaria* species for cultivation in coastal environments with fluctuating salinity levels, supporting sustainable aquaculture development. The study contributes to the understanding of salinity tolerance in economically important seaweeds and provides useful information for fisheries cultivation management. Future research should investigate the combined effects of salinity, nutrient availability, temperature, and light intensity to optimize seaweed productivity and cultivation efficiency.

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