

Unravelling Seasonal Environmental Controls on *Kappaphycus alvarezii* Growth in a Tropical Monsoonal Coastal Ecosystem

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Research Article

Keywords: seasonal variability, water-quality dynamics, generalised additive model, tropical seaweed aquaculture, Ambon Bay

Posted Date: October 14th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11133902/v1>

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Additional Declarations: No competing interests reported.

Abstract

Seasonal variability in environmental conditions can substantially influence the productivity and sustainability of tropical seaweed aquaculture. Yet, the relative contribution of individual water-quality variables to seasonal growth patterns remains poorly understood. This study investigated seasonal dynamics in water quality and their relationships with the growth of *Kappaphycus alvarezii* in Ambon Bay, Indonesia. 13 water-quality parameters and seaweed growth were monitored over multiple cultivation cycles in 2023–2024, and multivariate analysis was used to characterise seasonal environmental patterns. Generalised additive models (GAMs) were subsequently applied to assess the relationships between physicochemical variables and *Kappaphycus* growth. Water-quality profiles were distinctly clustered into two seasonal groups corresponding to the East monsoon (May–October) and West monsoon (November–April). The East monsoon was characterised by relatively high dissolved oxygen and alkalinity, whereas the West monsoon showed higher brightness, hardness, temperature, salinity, and total organic matter. Despite similar annual growth patterns among years, substantial monthly variation was observed. Mean growth during the East monsoon was $3.49 \pm 1.46\% \text{ day}^{-1}$, considerably higher than the $0.66 \pm 2.33\% \text{ day}^{-1}$ recorded during the West monsoon, with peak growth of approximately 5–6% day^{-1} occurring between June and August. GAM analysis indicated that temperature and nitrate had essentially linear relationships with growth ($\text{edf} = 1.000$) within the observed range. In contrast, phosphate and total organic matter exhibited nonlinear relationships, demonstrating that the influence of environmental conditions varied among physicochemical variables. The model explained 78% of the variance and 85.2% of the deviance in *Kappaphycus* growth, indicating a strong contribution of the measured environmental variables to growth variability. These findings demonstrate that seasonal water-quality dynamics, rather than monsoon season alone, determine the environmental suitability of *Kappaphycus* cultivation and its variation among environmental drivers. Seasonally adaptive water-quality management can therefore provide an important basis for optimising *Kappaphycus* production and strengthening the sustainability and climate resilience of tropical seaweed aquaculture.

Introduction

Global seaweed production is primarily sourced from aquaculture, which accounts for approximately 97% of total output (FAO 2024). Indonesia contributes about 25% of global production, making it the second-largest producer after China (FAO 2024). The genus *Kappaphycus alvarezii* is one of five genera of seaweed that collectively contribute over 33% of worldwide aquaculture production (Sultana et al. 2023). It is the leading sector in the blue economy and the main livelihood and income of rural coastal communities (Basyuni et al. 2024; van der Heijden 2022; Rimmer, 2021). This tropical red alga produces polysaccharide κ -carrageenan, which serves as a valuable resource in the food industry, cosmetics, biomedical applications, and wastewater treatment (Jabeen et al. 2025; Hayashi et al. 2017). Owing to expanded application and end-use demand, κ -carrageenan is estimated to account for 49.2% of the global market by 2026 (FMI, 2026).

Although *K. alvarezii* is cultivated extensively throughout tropical coastal regions, its growth and productivity can vary considerably across seasons. Such variability is associated with changes in environmental conditions including temperature, salinity, nutrient availability and other physicochemical characteristics of the cultivation environment (Hung et al. 2009; Barillé et al. 2025; Nurdin et al. 2025; Aslan et al. 2019). Seasonal variability in environmental conditions and the availability and quality of planting materials remain important constraints to consistent *K. alvarezii* growth and productivity, particularly in regions where environmental conditions fluctuate substantially across the cultivation cycle (Simatupang et al., 2021; Tahliluddin et al., 2024; van Oort et al., 2025).

Recent studies in Indonesia demonstrated marked differences in water quality and *K. alvarezii* growth between monsoon periods, with higher growth occurring during the wet monsoon, but accompanied by increased production risks such as ice-ice disease (e.g. Barillé et al., 2025). Field observations from several farming areas in Maluku over the past three years indicate that reserved planting materials frequently disappear during the non-cultivation season, including at a seaweed seedling centre in Ambon Bay (authors' field observations). Moreover, climate change and extreme weather exacerbate the seasonal effects on seaweed growth, which can result in crop failures and jeopardise the sustainability of *K. alvarezii* aquaculture production (Largo et al. 2017). Consequently, understanding how individual water-quality variables contribute to seasonal changes in seaweed growth is essential for improving the predictability and sustainability of *K. alvarezii* aquaculture

Previous studies have documented seasonal variation in *K. alvarezii* growth and production, but less attention has been given to how the seasonal dynamics of individual physicochemical variables determine the cultivation window and potentially contribute to the availability of planting material between production cycles. Moreover, it still lacks clarity due to the limited number of physicochemical parameters involved and the short and partial periods of study. This study aimed to assess seasonal changes in water quality parameters and *K. alvarezii* growth, examine their relationship, and identify the key water quality drivers at the local scale in Ambon Bay.

Materials and Methods

Study area

This study was conducted in seaweed farming sites in a semi-closed inner Ambon Bay, located at 3°38'20" S, 128°12'56" E (Fig. 1). It covers roughly 6 km² with an average depth of 30 m (Saputra and Lekalette 2016). The rainy season occurred between May and October, and the dry season was from November to April.

Data Collection

13 water quality parameters and seaweed growth data were collected three times per month, with an average of three sampling sites from January 2023 to December 2024. Water was sampled randomly at

depths of 0.50–1 m. Physicochemical parameters like temperature, salinity, pH, dissolved oxygen (DO), and turbidity were measured in situ using a HORIBA water quality multi-probe Model U-5000G. A 1 L sample of seawater was collected in a dark brown glass bottle from each site and was analysed in the Laboratory of the Marine Aquaculture Centre, Ambon, for nitrate, nitrite, ammonia, phosphate, alkalinity, hardness, and total organic matter (TOM), according to Strickland and Parsons (1972). Limit of detection of nitrate: 0.05 mg/L, nitrite: 0.002 mg/L, ammonia: 0.045 mg/L and phosphate: 0.05 mg/L.

Kappaphycus alvarezii was cultivated using the long-line method for 28 days per cycle, with an initial biomass of 100–120 g per cultivation unit. Samples were collected and weighed from three cultivation areas, and the initial and final biomass of the seaweed were recorded for each cultivation cycle. Growth rate was calculated using the equation: $\text{DGR (\% day}^{-1}\text{)} = [(WT/W_o)^{1/t} - 1] * 100$; where WT and W_o are the final and initial fresh weights (g), respectively, and t refers to the culture length in days (e.g. Mendes et al. 2022).

Statistical Analysis

Multivariate PERMANOVA was run on the normalised data and a Euclidean distance similarity matrix, with 999 permutations of the raw data, to assess water quality profiles across years and months and to identify key parameters contributing to these profiles. Principal component ordination (PCO) plots, with vector overlays based on Pearson correlations > 0.7 , were used to visualise the multivariate water quality data in two-dimensional space, grouped by year and month differences. Pairwise tests were used to establish significant differences between months, using Monte Carlo p-values to test interactions, with < 30 permutations of the raw data. All data were run in PRIMER v7 + PERMANOVA add-on with $\alpha = 0.05$ for a significant effect (Anderson and Willis 2003).

A univariate ANOVA was used to test the hypothesis that *K. alvarezii* growth varied between years and months. Multiple comparisons were run to compare the differences between months. All analyses used SPSS 30 at a confidence level of $\alpha = 0.05$.

Generalised additive models (GAMs) were run to examine the relationships between water quality parameters and seaweed growth. GAMs are statistical models that extend generalised linear models by allowing nonlinear relationships between the response and explanatory variables via smooth functions, thereby accommodating the complex and potentially non-linear nature of ecological relationships (Mainguy et al. 2026). Seaweed growth was modelled as a function of key water quality parameters, with smooth terms fitted for each predictor. Models were created using the mgcv R package (R Core Team 2020). Deviance explained, adjusted r^2 , and effective degrees of freedom (edf) were calculated. Model significance was assessed using F-tests.

Results

Seasonal Water Quality

The range value of water quality detected as follows: temperature (27–31°C), salinity (28–35 ppt), pH (7.80–8.39), DO (5–6 mg/L), nitrite (ND-0.08 mg/L), ammonia (ND-0.10 mg/L), nitrate (ND-0.71 mg/L), phosphate (ND-0.14 mg/L), hardness (237–451 mg/L), alkalinity (142–191 mg/L), turbidity (0.00-0.49 NTU), transparency (2–11 m), and TOM (16–65 mg/L) (Table 1, Supplementary Data 1).

Table 1
Range and mean values of water quality measured between 2023 and 2024.

No.	Parameter	East Monsoon (May to October)		West Monsoon (November to April)		P
		Range Value	Mean value ±SD	Range Value	Rata-rata ±SD	
1	Temperature (°C)	26,37 – 29,80	28±0,97	30,00– 31,30	30±0,32	2,25E-20 < 0,05
2	Salinity (ppt)	24,00– 34,00	31±2,66	21,00– 35,00	33±0,96	2,19E-06 < 0,05
3	pH	7,80 – 8,28	8±0,16	7,80 – 8,39	8±0,14	0,027 < 0,05
4	DO (mg/L)	5,00–6,13	6±0,33	4,80 – 6,00	5±0.28	1,68E-08 < 0,05
5	Ammonia (mg/L)	BD-0,14	0,02±0,033	LoD-1,06	0,07±0,24	0,114 > 0,05
6	Nitrite (mg/L)	BD-0,09	0,03±0,03	LoD-0,04	0,01±0,01	0,001 < 0,05
7	Nitrate (mg/L)	BD-0,04	0,01±0,012	LoD – 0,09	0,02±0,03	0,05 = 0,05
8	Phosphate (mg/L)	0,01 – 0,22	0,07±0,05	LoD – 0,21	0,08±0,05	0,093 > 0,05
9	Hardness (mg/L)	226–431	343±60	231–465	397±26	2,29x10 ⁻⁶ < 0,05
10	Alkalinity (mg/L)	126,07-201	173±14	128– 187,58	175±10	0.311 > 0.05
11	Brightness (m)	3.80-11.75	6±2,85	2.33–12.75	8±1,98	0,013 < 0,05
12	Turbidity (NTU)	0.00-0.24	0,15±0,57	0.00-3.16	0,01±0,04	0,067 > 0,05
13	TOM (mg/L)	9,48–59,25	35±12	28,00– 67,94	47±10	1,03x10 ⁻⁵ > 0,05
Note: LoD (below the limit of detection)						

Water quality varied between years and between months. Multivariate PERMANOVA revealed all physicochemical parameters fluctuated significantly between years (p = 0.0001 < 0.05) and months (p =

0.0001 < 0.05) (Fig. 2A, B). The PCO plots showed a clear separation of water quality profiles between 2023 and 2024, with high profiles observed in July 2023 and June 2024 (Fig. 2A). May, June, July, August, September, and October (the East monsoon) were grouped on the right side of the plot, with replicates within month (Fig. 2B). Some months have much greater variability within and among the others (Fig. 2B). Notably, September and October overlapped between sides and was marked by high alkalinity (Fig. 2B). The vector overlay demonstrates a strong influence of DO, particularly in June, July and August (Fig. 2B). However, November, December, January, February, March, and April (the West monsoon) were found to cluster and overlap to the left of the plot and had strong associations with high brightness, hardness, temperature, salinity and TOM (Fig. 2B). The range and mean value of water quality between seasons are shown in Table 1. The univariate analysis indicated that there was a significant difference between both seasons in the temperature ($p = 2.25e-20 < 0.05$), DO ($p = 1.68e-08 < 0.05$), hardness ($p = 2.29e-06 < 0.05$), salinity ($p = 2.19e-06 < 0.05$), TOM ($p = 1.03e-05 < 0.05$), nitrite ($p = 0.001 < 0.05$), brightness ($p = 0.013 < 0.05$), and pH ($p = 0.027 < 0.05$) (Table 1).

Seasonal Seaweed Growth

K. alvarezii growth exhibited pronounced seasonal variation among months, despite consistent interannual growth patterns (Fig. 3). Univariate ANOVA revealed no significant difference in *K. alvarezii* growth between 2023 and 2024, $p = 0.620 > 0.05$. However, it was significantly different across the months of the two tested years, $p = < 0.001$ and $p = < 0.001$, respectively (Fig. 3). A positive growth of *K. alvarezii* occurred from March to October in both years. The average growth between May and October (the East monsoon) was $3.49 \pm 1.46\% \text{ day}^{-1}$ (Fig. 3). *K. alvarezii* showed negative growth from November to February in both examined years. The average growth rate between November and April (the West monsoon) was $0.66 \pm 2.33\% \text{ day}^{-1}$ (Fig. 3). Interestingly, *K. alvarezii* growth in 2024 peaked earlier in 2024 than in 2023, with a higher level found in June, around $6\% \text{ day}^{-1}$ and in August at $5\% \text{ day}^{-1}$, respectively (Fig. 3).

Relationships between Water Quality and Seaweed Growth

The correlation between water quality profiles and *K. alvarezii* growth is shown in Table 2. The GAM model revealed that the primary water quality parameters that substantially influenced the growth of *K. alvarezii* were temperature ($p = 2e-16 < 0.05$), nitrate ($p = 1.84e-06 < 0.05$), phosphate ($p = 9.06e-05 < 0.05$) and TOM ($p = 1.02e-04 < 0.05$) (Table 2). The model explained 78% of the variance in *K. alvarezii* growth, while accounting for 85.2% of the deviance, indicating that the measured physicochemical parameters collectively provided a strong explanation of the observed variation in seaweed growth (Table 2). The GAM analysis indicated that temperature and nitrate exhibited essentially linear relationships with *K. alvarezii* growth, as reflected by the effective degrees of freedom (edf) of 1.000 for both smooth terms. Whereas phosphate (edf = 3.217) and TOM (edf = 3.388) exhibited nonlinear responses (Table 2).

Table 2
Generalised Additive Models (GAMs) approximate the significance of smooth terms

Water quality parameters	edf	Ref.df	F	p-value
Temperature	1.000	1.000	50.879	2e-16 ***
Salinity	1.670	2.036	2.077	0.132661
pH	1.000	1.000	2.196	0.144865
DO	2.067	2.465	0.424	0.510694
Nitrite	1.876	2.294	1.186	0.316509
Ammonia	1.332	1.542	2.280	0.081084
Nitrate	1.000	1.001	30.210	1.84e-06 ***
Phosphate	3.217	3.600	7.789	0.000906 ***
Hardness	2.030	2.401	2.590	0.067032
Alkalinity	1.000	1.000	0.000	0.996331
Turbidity	1.001	1.002	2.318	0.134078
Brightness	2.429	2.938	1.692	0.219520
TOM	3.388	3.788	5.459	0.001023 **

Discussion

Seasonal Water Quality

The distinct clustering of water-quality profiles into two seasonal groups indicates a clear monsoonal structuring of the physicochemical conditions in the study area. From May to October, corresponding to the East monsoon, the water-quality environment was characterised primarily by relatively high dissolved oxygen (DO) and alkalinity. Elevated DO may reflect enhanced water exchange, mixing, and atmospheric reaeration during the generally windier East monsoon period, while higher alkalinity may indicate differences in freshwater input, carbonate dynamics, and biological processes between seasons (Sabrina et al., 2020; Saputra & Lekalette, 2016; Salamena et al., 2021). In contrast, the November–April period, corresponding to the West monsoon, was characterised by higher brightness, hardness, temperature, salinity, and total organic matter (TOM). The combination of higher temperature and salinity suggests relatively different hydrological conditions during this period, potentially reflecting reduced dilution and changes in water exchange, while higher brightness indicates greater underwater light availability that may favour photosynthetic activity (Sabrina et al., 2020; Salamena et al., 2021; Salamena et al., 2022). The higher TOM during the West monsoon may reflect increased organic-matter inputs and/or changes in decomposition and nutrient cycling associated with seasonal rainfall and terrestrial

runoff. Overall, these results demonstrate that the *K. alvarezii* environment in the study area undergoes pronounced seasonal reorganisation, with the two monsoon periods presenting contrasting combinations of oxygenation, carbonate chemistry, light availability, hydrographic conditions, and organic enrichment. Such multivariate seasonal shifts are likely to contribute to the observed seasonal variation in *K. alvarezii* growth and should be considered when interpreting the relative influence of individual water-quality variables on seaweed productivity.

Seasonal Seaweed Growth

The markedly higher growth rate of *K. alvarezii* during the East monsoon indicates a strong seasonal influence on seaweed productivity. Mean growth during May–October ($3.49 \pm 1.46\%$ day⁻¹) was substantially higher than that recorded during the West monsoon ($0.66 \pm 2.33\%$ day⁻¹), demonstrating that the environmental conditions prevailing during the East monsoon were generally more favourable for *K. alvarezii* growth. The highest growth rates, reaching approximately 5–6% day⁻¹ between June and August, coincided with the period characterised by relatively high dissolved oxygen and alkalinity identified in the seasonal water-quality analysis. These conditions may have supported enhanced photosynthetic activity and physiological performance, particularly through improved oxygen availability and favourable carbonate conditions. Conversely, the markedly lower and highly variable growth during November–April suggests that conditions during the West monsoon were less favourable and potentially more stressful for *K. alvarezii*. The relatively large standard deviation during this period (2.33% day⁻¹) further indicates considerable temporal variability in growth, potentially reflecting fluctuating temperature, salinity, organic matter, light availability, and nutrient conditions. Importantly, the seasonal pattern suggests that *K. alvarezii* growth was not simply determined by a single environmental factor but likely resulted from the combined effects of multiple physicochemical conditions that changed concurrently between monsoon periods. The peak growth observed from June to August also indicates a potentially important seasonal window for maximising *K. alvarezii* production in the study area.

Relationships between Water Quality and Seaweed Growth

The seasonal growth pattern observed in the present study differs from that reported by Barillé et al. (2025) in South Sulawesi, where *K. alvarezii* exhibited higher growth during the West (Northwest) monsoon, coinciding with higher temperature, nitrate, and phosphate concentrations. In contrast, *K. alvarezii* in the present study showed substantially higher growth during the East monsoon, with peak growth between June and August. This apparent difference suggests that the influence of monsoon season on *K. alvarezii* growth is not consistent across Indonesian cultivation areas and may instead depend on the specific combination and magnitude of local physicochemical conditions. Indeed, Simatupang et al. (2021) demonstrated considerable spatial variation in *K. alvarezii* growth and production among Indonesian farming locations, accompanied by substantial differences in temperature, salinity, dissolved oxygen, nitrate, and phosphate. Therefore, the contrasting seasonal responses between Ambon Bay and South Sulawesi should not be interpreted simply as differences between “dry” and “wet” seasons, but rather as evidence that local water-quality regimes determine the environmental suitability of each cultivation period.

The present findings further support this interpretation, as the GAM analysis showed different response forms among environmental variables. Temperature and nitrate exhibited essentially linear relationships with growth, while phosphate and total organic matter showed nonlinear responses, suggesting that their effects remained relatively consistent across the observed environmental ranges. This pattern indicates that seasonal changes in temperature and nitrate may have contributed progressively to variations in *K. alvarezii* growth, rather than producing distinct optimum or threshold responses within the study period. In contrast, phosphate and TOM showed nonlinear relationships with growth, indicating that their effects were concentration-dependent and varied across the observed ranges. The nonlinear response to phosphate may reflect the importance of phosphorus availability for photosynthesis, energy metabolism, and cellular development, with growth potentially responding differently under low, moderate, and relatively elevated concentrations (Lapointe, 1986; Bossa et al., 2024). Similarly, the nonlinear response to TOM suggests that organic enrichment may have both positive and negative influences depending on its concentration and associated changes in microbial activity, oxygen demand, and nutrient cycling (e.g. Han et al., 2026). These contrasting response patterns may help explain the pronounced seasonal differences in *K. alvarezii*'s growth observed in the study, particularly the higher growth during the East monsoon and the reduced and more variable growth during the West monsoon. Thus, assessing seasonal seaweed productivity based solely on individual linear relationships may overlook important nonlinear responses to nutrient and organic-matter dynamics. Collectively, these results indicate that seasonal *K. alvarezii* productivity is governed by site-specific combinations of environmental conditions, highlighting the importance of locally resolved, season-specific water-quality assessments rather than applying generalised monsoonal cultivation windows across tropical seaweed farming regions.

Implication and Recommendation

The findings have important implications for the sustainability and resilience of *K. alvarezii* aquaculture in tropical monsoonal environments. The pronounced seasonal differences in growth and water-quality conditions indicate that sustainable production should move beyond uniform, year-round cultivation strategies toward seasonally adaptive and environmentally informed farm management. The substantially higher growth during the East monsoon, particularly from June to August, suggests a favourable production window that could be strategically prioritised for biomass accumulation. The lower and more variable growth during the West monsoon highlights that cultivation strategies should focus on reducing production risks and resource inefficiency. Importantly, the contrasting linear and nonlinear responses of temperature, nitrate, phosphate, and TOM demonstrate that environmental suitability cannot be defined by single-variable thresholds alone. Incorporating seasonal water-quality monitoring into decisions on planting, harvesting, stocking density, and farm-site management could therefore improve production efficiency while reducing crop losses and unnecessary expansion of cultivation areas. Such an adaptive approach could improve the efficiency and reliability of *Kappaphycus* cultivation in Ambon Bay while providing a practical framework for more sustainable, climate-resilient, and environmentally responsive tropical seaweed aquaculture.

Limitation

Several limitations should be considered when interpreting the findings of this study. First, although the study covered multiple cultivation cycles and years, the observations were conducted within a single coastal system, Ambon Bay, and therefore the identified seasonal relationships may not be directly transferable to other tropical seaweed cultivation areas with different hydrographic and climatic conditions. Second, the GAM analysis identifies associations between physicochemical variables and *Kappaphycus* growth but does not establish direct causality, particularly because several environmental variables may change simultaneously and potentially interact with one another. Third, the measured water-quality parameters did not encompass all biological and environmental factors that may influence seaweed performance, such as disease and epiphyte occurrence, nutrient uptake, light intensity at the thallus level, water movement, grazing pressure, and genetic differences among planting materials. In addition, the observed linear responses to temperature and nitrate, as well as nonlinear responses to phosphate and total organic matter, should be interpreted within the range of concentrations measured in this study and should not be assumed to represent universal thresholds for *Kappaphycus* cultivation. Future research should therefore incorporate longer-term monitoring across multiple cultivation sites, experimental validation of key environmental relationships, and additional biological and hydrodynamic variables to better distinguish the relative and interactive effects of environmental drivers on *Kappaphycus* productivity. Such approaches would strengthen the development of predictive, site-specific and seasonally adaptive management strategies for sustainable tropical seaweed aquaculture.

Conclusion

This study demonstrates that *Kappaphycus* growth is strongly influenced by seasonal variation in coastal water quality, with substantially higher and more consistent growth during the East monsoon than during the West monsoon. The contrasting linear and nonlinear responses to temperature, nitrate, phosphate, and total organic matter further indicate that seaweed productivity is shaped by multiple interacting environmental conditions rather than a single water quality factor. These findings highlight the importance of incorporating seasonal environmental dynamics into the planning and management of tropical seaweed aquaculture. Seasonally adaptive cultivation strategies, supported by regular water-quality monitoring and appropriate timing of planting and harvesting, can improve production efficiency, reduce crop losses, and minimise unnecessary pressure on global coastal ecosystems. Such approaches will become increasingly important for maintaining the productivity, environmental sustainability, and climate resilience of tropical seaweed aquaculture under growing environmental variability and climate change.

Declarations

DECLARATION OF CONFLICT OF INTEREST

The authors declare that they have no conflict of interest that could have influenced the research, authorship, or publication of this manuscript.

AUTHOR CONTRIBUTION STATEMENT

All authors contributed to this study, approved the final version of the manuscript and agreed to be accountable for the work. **EJ**: Conceptualisation, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualisation, Writing – original draft, review & editing. **S**: Data curation, Funding acquisition, Investigation, Methodology, Resources, Writing – review & editing. **BJP**: Conceptualisation, Data curation, Investigation, Methodology, Supervision, Validation, Writing - review & editing. **JWL**: Investigation, Project administration, Methodology, Visualisation, Writing - review & editing.

FUNDING

This research was completed with funding from the Higher Education Centre of Priority Research Program, Institute for Research and Community Service 2025, University of Pattimura, No.1048/UN13/SK/2025.

Acknowledgment

The authors gratefully acknowledge the support and collaboration of the Ambon Marine Aquaculture Centre, Maluku, Indonesia, for providing access to the seaweed cultivation areas and facilitating field activities throughout the study period. We particularly appreciate the assistance of the technical staff and field personnel who supported seaweed cultivation, sampling, and environmental monitoring. Their cooperation and technical support were essential to the successful completion of this research.

Data Deposit

<https://drive.google.com/drive/folders/1gLycqpF9KzZ7lvizSqGb425WGicqX1FP>

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Figures

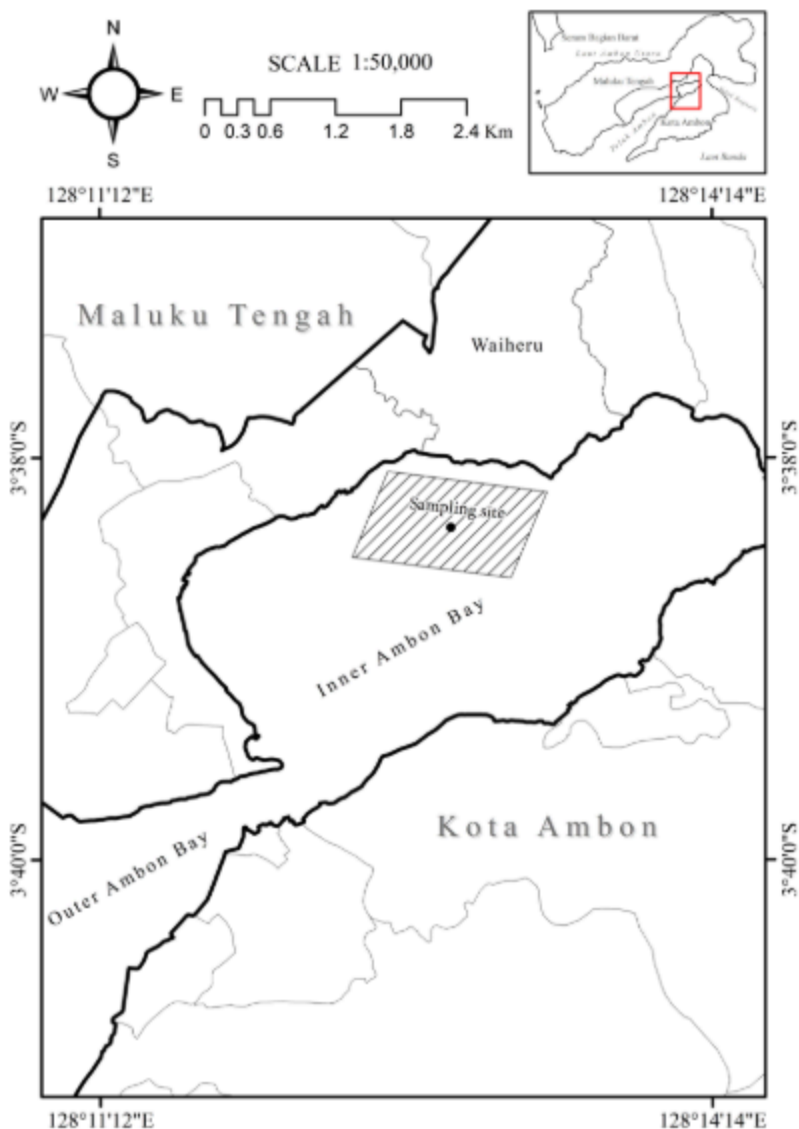


Figure 1

A map of the study area with sampling sites in Ambon Bay.

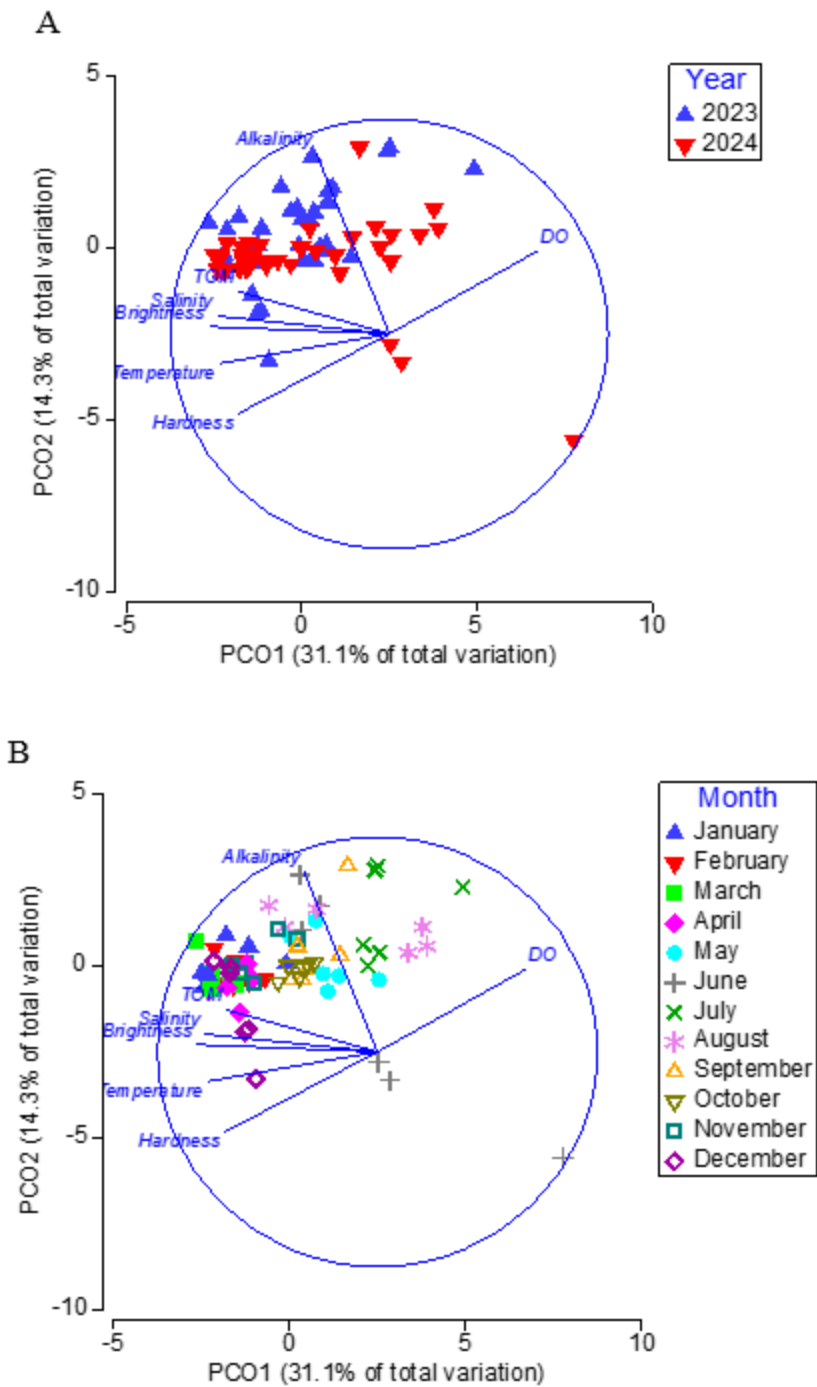


Figure 2

Principal component ordination (PCO) plots of water quality between years (A) and months (B) based on Euclidean distance similarity matrix of normalised data with vector overlay from Pearson rank correlation (>0.7).

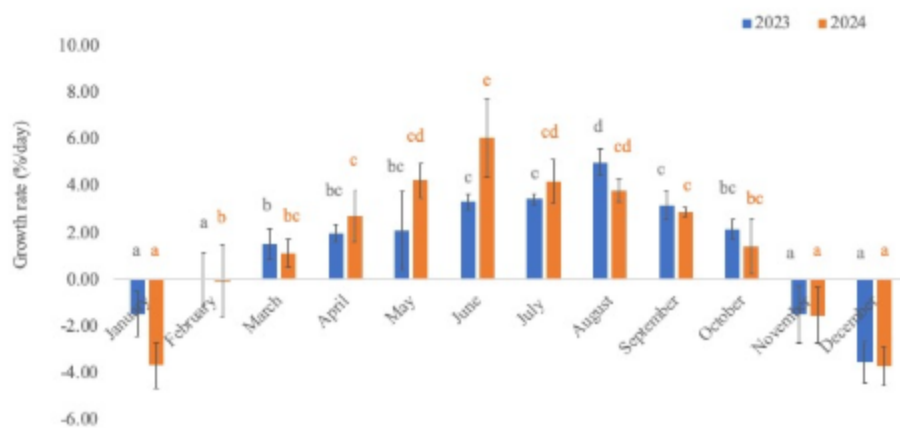


Figure 3

The mean $\pm$ SD of Kappaphycus growth each month in 2023 (blue bar) and 2024 (red bar) in Ambon Bay. The letters show the difference between months.

Supplementary Files

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- [SupplementaryData.docx](#)