

# Comparative Evaluation of *Eucheuma denticulatum* Productivity in Floating Raft Systems: Integrated versus Monoculture Systems in Kwale County, Kenya

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**Abstract**—The research study aimed to compare biomass productivity between these systems using polynomial regression to model seaweed growth. Seaweed was cultivated over 49 days using floating rafts, with twelve seeded ropes per raft and one unseeded control line. In the IMTA setup, rafts were placed approximately 30 meters from the fish cages stocked with *Siganus sutor*. Environmental parameters, including temperature, pH, salinity, dissolved oxygen, and total dissolved solids, were measured and found to be within acceptable ranges for seaweed farming. At Kijiweni, dissolved oxygen and salinity levels were lower than at Kibuyuni. Growth data fitted well with polynomial models ( $R^2 \approx 0.99$ ), allowing estimation of intermediate biomass trends. Overall, the monoculture system outperformed the IMTA system, with substantially higher growth rates and yields, while IMTA results remained within biologically plausible ranges reported in prior studies. The findings suggest monoculture systems offer higher short-term yields while IMTA systems may provide long-term ecological benefits. The study highlights the importance of environmental conditions and system configuration in seaweed farming. It indicates the need for longer-term studies to fully assess IMTA's potential for supporting coastal livelihoods.

**Keywords:** Integrated Multi-Trophic Aquaculture Systems (IMTA), monoculture, *Siganus sutor*, *Eucheuma denticulatum*, polynomial regression analysis, coastal marine

## 1 Introduction

Seaweed farming is among the most sustainable aquaculture practices globally, with annual production exceeding 36 million tons and a market value of over \$17 billion (FAO, 2022). Asia leads the industry, producing more than 97% of global seaweed, while Africa contributes less than 0.3%, despite its vast coast line and the potential to improve food security and coastal livelihoods (FAO, 2022; Msuya, 2021).

In East Africa, seaweed farming began in the 1980s, but productivity remains low averaging 1.2 kg/m<sup>2</sup> per cycle compared to the 3 to 5 kg/m<sup>2</sup> achievable under optimized conditions (Msuya, 2020). Growth is constrained by several factors, including rising ocean temperatures, variability in nitrogen and phosphorus availability, and the continued reliance on mono-aquaculture systems. Obura et al. (2022) reported an increase of approximately 0.14°C per decade in the Western Indian Ocean, highlighting the magnitude of thermal stress in

the region. These challenges are particularly significant for small-scale farmers in Kenya's Kwale County, who constitute the majority of the country's seaweed producers (Msuya, 2016).

*E. denticulatum* locally referred to as spinosum, contains carrageenan and agar, polysaccharide compounds widely used across food, pharmaceutical, cosmetic, and industrial sectors (Angka & Suhartono, 2000; Reine & Trono, 2002). Carrageenan, formed in the cell walls of red algae, functions as a stabilizer, thickener, and gelling agent, while agar is used as a food additive, thickener, and rehydrating agent. These properties make seaweed species an economically important species whose improved productivity could directly benefit coastal livelihoods.

Integrated Multi-Trophic Aquaculture (IMTA) has emerged as a promising model to address productivity challenges in seaweed farming. By combining species from different trophic levels such as rabbitfish and seaweed, IMTA systems establish nutrient recycling loops where waste from one species serves as input for another. Seaweeds in these systems absorb dissolved inorganic nutrients, primarily nitrogen and phosphorus, enhancing growth while also mitigating eutrophication (Chopin et al., 2012). Studies from temperate regions have demonstrated significant gains, with IMTA improving seaweed biomass yields by 22 to 38% (Abreu et al., 2011; Handå et al., 2013).

In African contexts, research on IMTA remains limited. A few pilot studies in South Africa and Madagascar have demonstrated the feasibility of IMTA systems, particularly with shellfish and seaweeds, noting improved nutrient cycling and economic returns (Troell et al., 2009; Rougier et al., 2020). However, these examples remain isolated. In East Africa, there

are limited number of published studies to date that have evaluated IMTA models that integrate finfish and *E. denticulatum*. Kenya's aquaculture sector has seen the recent emergence of rabbitfish farming along the coast especially in Kwale county (Mwaluma et al., 2021), yet these systems operate independently of existing seaweed farms. In Tanzania and Zanzibar, where seaweed farming is more established, IMTA trials have not moved beyond preliminary discussions or conceptual frameworks (Msuya, 2021).

Seaweed cultivation along the Kenyan coast employs both fixed and floating methods, each adapted to specific environmental conditions and resource availability. The most commonly used fixed technique is the off-bottom method, which is prevalent in shallow intertidal areas of Kwale and Kilifi counties due to its simplicity and cost-effectiveness (Msuya, 2013; Kimathi et al., 2018). Another fixed method is the long-line technique, typically applied in deeper, open waters requiring depths of up to 10 meters, to reduce competition from epiphytes and optimize light exposure (Msuya, 2013). Floating methods, on the other hand, include raft systems constructed from locally available materials such as bamboo or high-density polyethylene (HDPE) pipes. In these systems, seaweed seedling fragments are tied to polythene strings or tubes suspended in the water column, including variations such as the tubular net method (Mirera, 2011; Kimathi et al., 2018).

The limited availability of local research offers an opportunity for deeper analysis into whether nutrient-rich effluents from rabbitfish cultivation can influence seaweed yields under an integrated system in coastal open waters. This kind of data, is significant to Kenya to help it take advantage of scalable, sustainable innovation that aligns with both economic and

environmental goals. A key problem facing seaweed farming in Kwale County is the limited productivity of conventional mono-aquaculture seaweed cultivation systems, which may not fully utilize available nutrients in the marine environment. This study therefore, investigates whether an IMTA system can enhance *E. denticulatum* productivity compared to traditional mono-aquaculture systems.

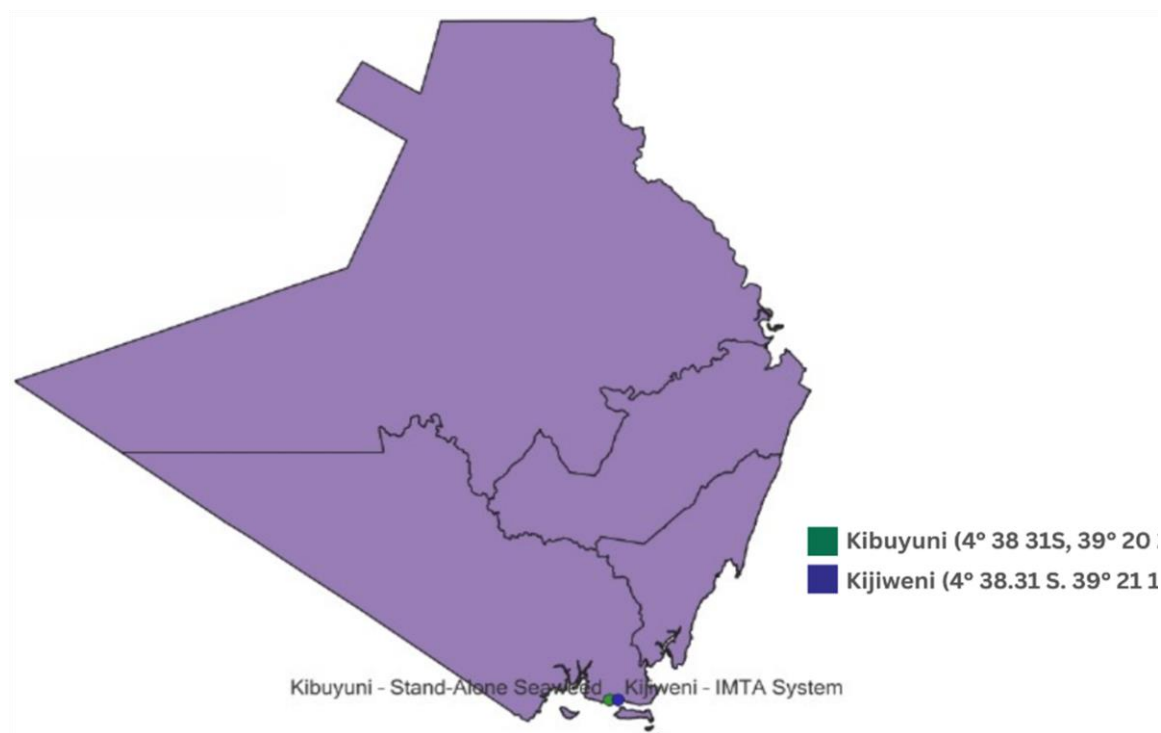
## 2 Material and Methods

### 2.1 In Study area and site characterization

This study was conducted in the coastal marine waters of Kwale County, Kenya, specifically in the villages of Kibuyuni (4° 38' 31" S, 39° 20' 29" E) and Kijiweni (4° 38' 31" S, 39° 21' 15" E). Kibuyuni served as the site for the monoculture cultivation system, while Kijiweni was selected for the Integrated Multi-Trophic Aquaculture (IMTA) system of rabbitfish and seaweed (Figure 1). A suitability mapping transect analysis was conducted prior to the study. The analysis physicochemical parameters in both Kibuyuni and Kijiweni and additionally assessed geographical factors which displayed gently sloping topographies with coral stone outcrops, which are suitable for anchoring fish cages and seaweed rafts (Table 1).

**Table 1**—Environmental Parameters obtained during the transect analysis

Parameter	Kibuyuni Range	Kijiweni Range
Temperature (°C)	25.78 – 26.59	26.78 – 28.65
Salinity (ppt)	34.14 – 35.37	31.15 – 34.49
pH	7.87 – 8.10	7.68 – 7.95
Dissolved Oxygen (mg/L)	6.17 – 8.19	4.12 – 6.56
Total Dissolved Solids (mg/L)	18,920 – 24,302	17,829 – 22,456



**Figure 1**—A Map of Kwale County indicating the two sampling sites

The physicochemical conditions at the two sites were found to be highly suitable for Integrated Multi-Trophic Aquaculture (IMTA). Temperatures at both sites ranged between 25.78°C and 28.65°C, aligning well with the optimal range for seaweed growth (25–30°C), as supported by Chopin (2013) and FAO (2018). Salinity levels were stable and within the typical marine range (31.15–35.37 ppt), supporting the physiological requirements of both seaweed and rabbitfish (Largo et al., 2020). The pH values, ranging from 7.68 to 8.10, were ideal for maintaining nutrient availability and ensuring healthy aquatic life (FAO, 2018). Dissolved oxygen levels varied between 4.12 mg/L and 8.19 mg/L, indicating sufficient oxygenation to support marine organisms, including fish and

seaweed (Troell et al., 2009). Total dissolved solids (TDS) readings between 17,829 mg/L and 24,302 mg/L further suggested a balanced mineral composition of the water. These conditions collectively created an environmentally favorable experiment setting.

This work was done under the Blue Empowerment Project which aims to test integrated aquaculture innovations along the Kenyan coast. The project's assessment was inclusive of the 45–50-day seaweed cultivation cycle implemented during the months of April and May 2025.

## 2.2 Selection of seaweed seedlings

For proper selection, *E. denticulatum* seedlings were sourced from local farms in Kibuyuni and Kijiweni to ensure environmental adaptation. The selection followed criteria described by

WWF (2014), where fragments needed to be 25–30 days old, had multiple branches, no spots or lesions, were not grazed or overgrown with epiphytes, and were fresh, flexible, and rich in young thalli. The selected fragments were tied directly onto cultivation polyethylene 5mm ropes using the tie-tie method, with 20 fragments attached to the tie-ties and spaced 15 cm apart along each rope. The initial weight of each rope was obtained using a calibrated weighing scale this included the control rope on each raft. This method aligns with practices described by Msuya (2013), who recommends the tie-tie technique for uniform planting and effective monitoring in small-scale tropical seaweed farming.

### 2.3 Experimental design and data collection

A quantitative experimental design evaluated and compared the biomass productivity of *E. denticulatum* in the two cultivation systems. In both locations, seaweed was cultivated using the floating raft method. Each bamboo raft measured approximately 3.6 meters by 3.6 meters and carried 13 horizontal cultivation ropes. Of these, 12 ropes were planted with seaweed using 20 evenly spaced tie-ties, and the 13th rope was left bare to serve as a control. The monoculture system comprised only seaweed floating-rafts.

The IMTA system included a fish cage measuring 15 by 5 meters, subdivided into three equal compartments, each 5 by 5 meters in size. The cage frame was constructed from high-density polyethylene (HDPE) pipes, with joints reinforced using stainless steel fittings. It was securely anchored to the sea floor at a depth of 6 meters. The compartments accommodated *S. sutor*, which fed on standard diet of seaweed dictated by the fish body weight. The seaweed rafts were installed approximately 30 meters

away to allow for optimal nutrient absorption within the IMTA system.

### 2.4 Data and statistical analysis

The study employed basic statistical analysis to evaluate seaweed productivity, including the calculation of means and growth indices. Initial and final wet weights of seaweed ropes were recorded to assess biomass accumulation. These measurements were then used to quantify productivity differences between the IMTA and monoculture systems. The growth indices, commonly applied in aquaculture research, were used to standardize comparisons, account for variations in initial weight, and provide interpretable metrics for daily and relative growth as well as yield per area.

### 2.5 Polynomial Regression Model

To estimate biomass accumulation over time, a polynomial regression model was adapted for this research study. This model was developed for *E. cottonii* by Firdausy et al. (2020) in their study expressed as:

$$Y = Y_0 + 49.73 t - 0.29 t^2$$

Where Y is the predicted wet weight (g) and t is time (days). Firdausy et al. reported an  $R^2$  of 0.997, demonstrating the utility of polynomial models in predicting seaweed growth and supporting production and profitability estimates. Their research proved that by using the model, seaweed farmers can estimate the progress of seaweed weight, and also production and profitability of *E. cottonii* cultivation.

In the current study, the model was modified to fit the initial weight data collected for *E. denticulatum* in Kwale, since only the initial and final weights were recorded during the experimental phase. Polynomial regression models were fitted using average biomass at days 0, 15, 30, and 49 for the two cultivation systems as follows:

IMTA System:

$$Y(t) = 546.25 + 5.485t + 0.377t^2$$

Monoculture System:

$$Y(t) = 770.42 + 24.58t + 1.56t^2$$

Where Y(t) is the predicted wet weight (g) at time t (days). Both models exhibited a high degree of fit of  $R^2 \approx 0.99$  and were used to estimate average growth rates and yields at intermediate time points. Using these model predictions allowed the study to generate continuous growth curves from limited sampling points, enabling a more precise calculation of growth indices at specific intervals rather than relying solely on initial and final weights.

## 2.6 Growth Indices

Based on the output of the model predictions, three key growth indices were calculated: Daily Growth Rate (DGR), Specific Growth Rate (SGR), and plant yield (Y) for the period of cultivation for both systems. The DGR was calculated as the average daily increase in wet weight (g/day), while SGR expressed the relative growth rate as a percentage per day using the natural logarithm of final and initial weights. Yield per square metre was computed by summing the final wet weights of all cultivated ropes within a  $3.6 \times 3.6$  m raft and dividing by the total area ( $12.96 \text{ m}^2$ ), then converting the result to kilograms.

These indices offered complementary perspectives: DGR measured the average daily biomass increase, SGR reflected relative growth independent of starting size, and yield represented production per unit area. By combining these indices with model predictions, growth rates at intermediate time points could be estimated, enabling comparison of performance between the two cultivation systems throughout the study period. It is also

consistent with methodologies commonly adopted in seaweed aquaculture research for comparing performance across systems and environmental conditions.

Daily Growth Rate (DGR) as used by Hurtado et al., (2019)

$$DGR = \frac{(W_t - W_o)}{W_o} * \frac{100}{t}$$

Where:

$W_t$  = final weight (kg)

$W_o$  = initial weight (kg)

t = duration of culture (days)

Specific Growth Rate (SGR) as used by Yong et al., 2014

$$SGR = \frac{(\ln W_t - \ln W_o)}{t} * 100$$

Where:

ln = natural logarithm

$W_t$ ,  $W_o$  and t as above.

Plant yield (Y) in  $\text{kg/m}^2$  (Hurtado et al. 2001)

$$Y = \frac{(W_t - W_o)}{A_t}$$

Where:

$W_t$  = final weight of seaweed (kg)

$W_o$  = initial weight of seaweed (kg)

$A_t$  = total area of the plot ( $\text{m}^2$ )

In order to identify variations in growth patterns and productivity between the IMTA and monoculture systems, these indices were then examined. The study was able to take into consideration both temporal growth dynamics and overall production by combining DGR and

SGR with yield per area. This resulted in a reliable evaluation of system performance.

## 2.7 Statistical analysis

To determine whether differences in productivity between the IMTA and monoculture systems were statistically significant, independent samples t-tests were conducted using R statistical software (version 4.5.1; R Core Team, 2021). Welch's t-test, which does not assume equal variances between groups, was used to compare mean values for DGR, SGR, and yield across the two systems. All tests were performed at a 95% confidence level, with differences considered significant at  $p < 0.05$ . Standard errors (SE) for growth indices were derived from the polynomial model predictions at days 15, 30, and 49. SE was calculated as the standard deviation of interval-based growth rates divided by the square root of the number of intervals ( $n = 3$ ). This approach allowed the study to present not only point estimates of growth but also measures of variability across the cultivation period.

## 3 Results

The polynomial regression analysis revealed clear and consistent differences in growth performance between the IMTA and monoculture systems for *E. denticulatum* (Table 2). Looking at the model predictions, the monoculture system at Kibuyuni outperformed the IMTA system at Kijiweni in all key analysed growth indicators.

The average initial wet weight of seaweed in the IMTA system was 546.25 g per rope, compared to 770.42 g in the monoculture system (Table 3). At the end of the 49-day cultivation cycle, the predicted average yield reached 1270.42 g per rope in the IMTA setup and 5402.50 g per rope in the monoculture setup (Table 2). This translated to average yields over

the full period of 920.59 g (IMTA) and 2675.26 g (monoculture).

The predicted Daily Growth Rate (DGR), based on interval-specific estimates from polynomial models, was significantly higher in

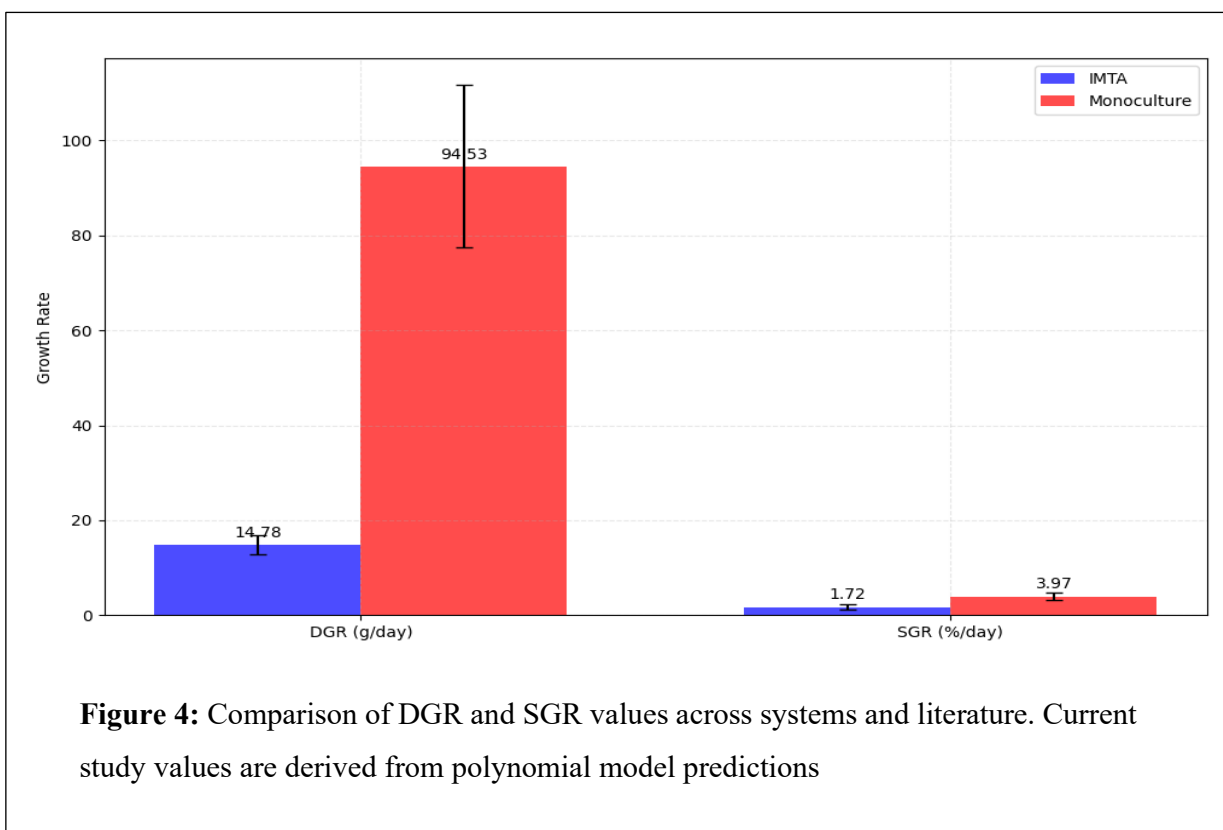
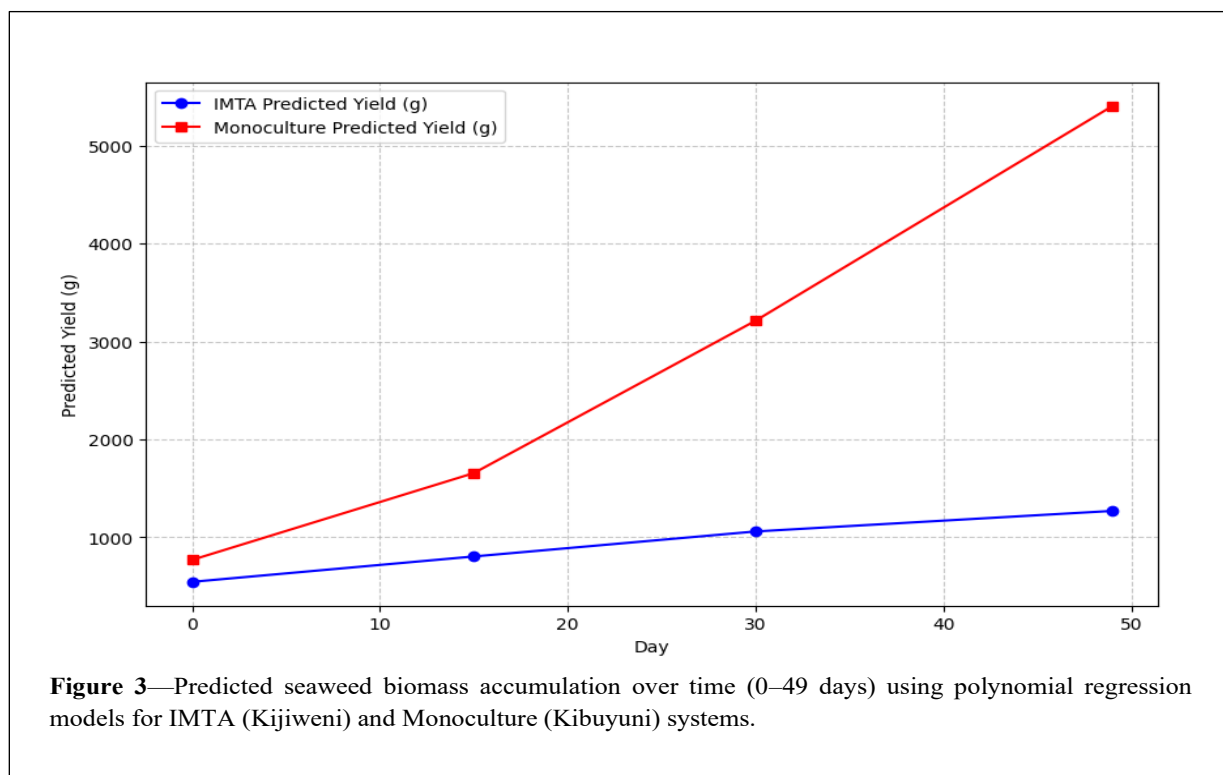
**Table 2**—Polynomial model predictions

Day	IMTA predicted yield (g)	Monoculture predicted yield (g)
15	805.30	1656.50
30	1060.40	3211.60
49	1270.42	5402.50

**Table 3**—Growth indicators based on polynomial model averages

Growth Indicator	IMTA (Kijiweni)	Monoculture (Kibuyuni)
Ave. initial weight (g)	546.25	770.42
Avg predicted yield (g)	920.59	2675.26
Av DGR (g/day)	$14.78 \pm 2.03$	$94.53 \pm 17.14$
Av SGR (%/day)	$1.72 \pm 0.47$	$3.97 \pm 0.70$

the monoculture system at  $94.53 \pm 17.14$  g/day than in the IMTA system,  $14.78 \pm 2.03$  g/day. Similarly, the Specific Growth Rate (SGR) in monoculture at  $3.97 \pm 0.70\%$ /day was more than double that observed in the IMTA setup  $1.72 \pm 0.47\%$ /day, indicating faster relative biomass accumulation under monoculture conditions (Figure 4). Welch's t-test showed statistically significant differences between the systems for DGR ( $p < 0.001$ ), SGR ( $p = 0.002$ ), and yield ( $p < 0.001$ ).



## 4 Discussion

This study aimed to compare the productivity of *E. denticulatum* cultivated under an Integrated Multi-Trophic Aquaculture (IMTA) system in Kijiweni and a monoculture system in Kibuyuni. The observed differences in growth performance across the two sites appear to be strongly influenced by local environmental conditions.

Despite the fact that IMTA systems are intended to improve nutrient recycling by co-cultivating with finfish, the absence of production increases at Kijiweni raises the possibility that these advantages were not achieved during the brief 49-day study. The fish cages may have generated too little nutritional waste to have a major impact on seaweed growth, or physical or chemical constraints like current velocity and diffusion limitations, may have limited the seaweed's ability to absorb nutrients. This outcome is in line with Troell et al. (2009), who stress that site-specific hydrodynamics and culture design are just as important to IMTA success as trophic connections.

According to the results, the monoculture system performed better than the IMTA configuration on every growth metric. The monoculture system's noticeably greater DGR and SGR indicate that, in the absence of interspecies interactions, *E. denticulatum* grew more quickly and accumulated more biomass. These outcomes are consistent with earlier research by Firdausy et al. (2020), which showed how well polynomial models could stimulate the growth of seaweed. Specifically, their model  $Y=Y_0+49.73t-0.29t^2$  for the cultivation of *E. cottonii* in the Karimunjawa Islands yielded a high coefficient of determination  $R^2 = 0.997$ , which was

comparable to the strong match found in our polynomial regressions.

Furthermore, Welch's t-tests validated the significant differences between the two systems. According to these tests, the monoculture system had a significantly greater yield ( $p < 0.001$ ), specific growth rate ( $p = 0.002$ ), and daily growth rate ( $p < 0.001$ ). This indicates that the discrepancies were probably not the result of chance. The data clearly indicate that the system design and local conditions had a significant impact on the seaweed growth, despite the fact that the study employed one raft per site.

The pre-experimental environmental parameters collected in **Error! Reference source not found.** also played a significant role in explaining the observed differences in growth performance. Kibuyuni exhibited higher dissolved oxygen (6.17–8.19 mg/L) and stable salinity (34.14–35.37 ppt), both known to enhance seaweed metabolism and nutrient absorption (Largo et al., 2020). Meanwhile, the lower DO levels (4.12–6.56 mg/L) and slightly lower salinity (31.15–34.49 ppt) at Kijiweni may have contributed to suboptimal physiological conditions for seaweed, particularly in an IMTA context where nutrient flow is shared with fish.

Seaweed rafts were placed 30 meters away from the fish cages in our set-up to minimize interference and provide the best possible distance for the dispersion of nutrients. This arrangement probably avoided adverse interactions, preserving ecological advantages without lowering the effectiveness of seaweed growth. More favorable environmental conditions at the Kibuyuni site, such as improved water circulation, or nutrient sufficiency, wave movement, and possible competition or stress factors brought about by the presence of rabbitfish cages in the IMTA

setup, could all be reasons for this result. The seaweed production may be significantly impacted by micro-environmental variability, as seen by the negative growth seen in one sample in Kibuyuni.

To place our findings within the context of current seaweed aquaculture literature, it is essential to compare the observed SGR values with those from recent and historical studies. Our study recorded a specific growth rate (SGR) of  $3.97 \pm 0.70\%$  per day in the Kibuyuni monoculture system and  $1.72 \pm 0.47\%$  per day in the Kijiweni IMTA system (Figure 4). These results are in line with Yahya et al. (2020), who reported an SGR of  $3.42 \pm 0.18\%$  for *E. denticulatum* grown on deep-water floating rafts in Tanzania closely resembling the Kibuyuni outcome. The study also found slightly lower performance on off-bottom systems ( $3.01 \pm 0.27\%$ ), suggesting that floating raft systems tend to favor higher productivity.

Kimathi et al. (2018), in a study along the Kenyan coast, reported a wide SGR range of 0.9–10.2% for floating raft systems and 0.2–7.3% for off-bottom methods. Our Kibuyuni result falls well within this range, highlighting optimal conditions for monoculture. Meanwhile, the lower Kijiweni SGR values are still within documented ranges for floating raft systems (Yahya, et, al 2020), under more variable conditions, suggesting that the IMTA setup may require refinement to reach its full potential. These regional studies reinforce the idea that both site selection and integration design significantly influence *E. denticulatum* performance.

In a more controlled environment, Gerung and Ohno (1997) observed an average SGR of  $2.73 \pm 0.43\%$  in Japan for a brown strain of *E. denticulatum* under floating raft cultivation. While slightly lower than the Kibuyuni result,

this value highlights the role of geographic, genetic, and environmental variability. Earlier studies also reinforce these findings. Hwang et al. (2006) and Trono (1992) reported SGRs between 3.0–5.0% under tropical conditions for *E. denticulatum*, which closely aligns with our Kibuyuni system. Ask and Azanza (2002) reported monoculture DGRs ranging from 35–95 g/day in similar setups, comparable to the  $94.53 \pm 17.14$  g/day observed in the Kibuyuni monoculture system, and  $14.78 \pm 2.03$  g/day in the Kijiweni IMTA setup (Figure 4), both based on polynomial model predictions.

These cross-study comparisons collectively affirm that our observed growth metrics are consistent with expected biological potential and underscore the importance of site optimization when implementing IMTA or monoculture systems. To act as a control, the 13th rope on each raft in both systems was left unseeded. The biomass of these ropes increased from 100 g to 160 g at Kijiweni and from 135 g to 150 g at Kibuyuni, most likely due to environmental factors such as epiphytic development, sediment deposition, microbial colonisation, and tiny invertebrate activity. Including this control allowed for the differentiation of cultivation-related growth from background environmental influences, ensuring that the observed increases in biomass on seeded ropes reflected the effects of the experimental treatment rather than extraneous accumulation, which is consistent with a rigorously controlled experiment design.

The polynomial models used in this study further strengthened the reliability of the findings. With an  $R^2$  value close to 0.99 for both systems, the models accurately predicted intermediate biomass values (e.g., at days 15 and 30), enabling fine-resolution comparisons and reducing the uncertainty of long-term

projections. This modeling approach proved especially valuable in estimating standard errors and understanding yield dynamics across the cultivation cycle.

Overall, the polynomial models used in this study provided yield estimates that are both biologically realistic and statistically consistent with models from existing literature. It is also important to note that the IMTA system, despite showing lower short-term growth rates, offers potential ecological benefits through integrated nutrient recycling, diversification of output, and reduced environmental impact.

According to Neori et al. (2004) and Troell et al. (2009), IMTA systems can improve water quality and system resilience by absorbing dissolved nutrients released by finfish culture. Although the nutrient enhancement from rabbitfish was not visibly reflected in seaweed yield over the 49-day trial, these ecological services may manifest more clearly over longer cultivation cycles or in systems designed with optimized nutrient flow and spatial configuration. The difference in growth outcomes between IMTA and monoculture systems reflects the influence of site conditions and farming design, reaffirming that optimized monoculture systems can yield high short-term returns, while IMTA systems offer broader sustainability benefits.

## 5 Conclusion

The predicted yield trends indicate that, while monoculture systems of *E. denticulatum* produced higher yields over the 49-day period, IMTA systems still provide a stable growth trajectory, suggesting potential benefits in terms of ecosystem integration and long-term sustainability that may not be captured by short-term yield comparisons. The use of polynomial modeling in seaweed cultivation was supported by its ability to produce accurate forecasts of

seaweed biomass at intermediate growth stages. The study polynomial model fits and growth results matched literature-based estimates when compared to published models, confirming the modeling methodology and the influence of the environment factors on growth.

The results emphasize the significance of tailoring IMTA's design and implementation to site-specific conditions such as water flow, nutrient concentration and availability and ecological or species compatibility among co-cultured species, without undermining the technique's wider potential as a sustainable aquaculture approach. When set up under the right conditions, monoculture systems is still a dependable and productive technique that, in certain situations, may produce better results than more elaborate integrated systems. IMTA systems offer wider ecological benefits, such as sustainability and nutrient recycling, even though monoculture systems are more productive in the short term. Our models' high accuracy of  $R^2 = 0.99$  validates their usefulness in aquaculture planning. This reported robust experimental design and interpretation were facilitated by the use of environmental profiling and unseeded control ropes.

## 6 Limitation of the study

The primary drawback of this study was that it only examined a single cultivation cycle for 49 days, which may have left out long-term seasonal effects or cumulative nutrient interactions that are specific to IMTA systems. Additionally, the robustness of statistical comparisons was limited because only one replicate raft per system was examined. Although they were not measured, environmental factors such as wave velocity and nutrient concentrations probably had an impact on biomass output, particularly at Kijiweni. In the IMTA system, conclusive findings

regarding nutrient transfer from fish to seaweed are limited by the lack of nutrient profiling. Interpreting variations in growth performance between locations would be improved by more thorough environmental monitoring.

## 7 Futuristic areas of research

In the future research should involve studies which are multi-dynamic in nature to monitor seasonal changes, nutrient dynamics, and water column movement to better understand the performance of IMTA systems in different coastal environments. Investigating varying fish densities, raft-fish cage distances, and species combinations could help optimize IMTA design. Additionally, integrating direct nutrient sampling such as, nitrate, phosphates would allow for more accurate assessments of nutrient transfer efficiency and its influence on seaweed growth. Moreover, studies should investigate different seaweed cultivation methods that can be incorporated in to integrated systems or better productivity when grown in isolation.

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