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Growth and Survival of the Seaweed *Eucheuma cottonii* Cultivated Using a Verticulture System

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ABSTRACT

Eucheuma cottonii is one of the most widely cultivated seaweeds in the Asia–Pacific region, including Indonesia. Various farming techniques have been developed to enhance its production, yet the use of verticulture—multi-tiered cultivation structures—remains limited for this species. This study is one of the first to systematically evaluate the application and effectiveness of a multi-tiered verticulture system for *E. cottonii* cultivation, specifically analyzing the effect of depth gradient within this novel structure. The experiment was conducted from June to September 2025 in Kodek Bay, North Lombok, Indonesia, using a completely randomized design with four depth treatments and three replicates: 0 m (P0), 1 m (P1), 2 m (P2), and 3 m (P3). Seedlings with an initial weight of 30 g were used. The measured parameters included absolute weight gain, specific growth rate, thallus length, thallus number, survival rate, and water quality. Data were analyzed using analysis of variance (ANOVA) followed by Duncan's multiple range test in SPSS. The results showed that depth treatments had a significant effect on absolute weight gain, specific growth rate, thallus length, thallus number, and survival of *E. cottonii*. Water-quality parameters remained within optimal ranges across all treatments, with temperature 27–28°C, pH 8.06–8.07, salinity 34–35 ppt, and light intensity 3,061–5,607 lux. The best performance was obtained at the 0-m depth (P0), yielding an absolute weight gain of 29.29±2.14 g, thallus length of 1.1±0.12 cm, 67±1.53 thalli, a specific growth rate of 2.27±0.12% day^{-1}, and a survival rate of 88.9±0.58%. Based on these findings, the 0-m depth (water surface) is definitively recommended for *E. cottonii* farming using the verticulture system in Kodek Bay and similar shallow waters with equivalent oceanographic conditions.

Keywords: *E. cottonii*, depth, growth, Kodek Bay, verticulture

INTRODUCTION

Seaweed is one of the major fishery commodities exported in both dried and processed forms. As a macroalga, seaweed lacks differentiated roots, stems, and leaves; instead, its body consists of a thallus [1]. *Eucheuma cottonii* is characterized by flattened or cylindrical thalli with smooth surfaces, while its primary and secondary branches form dense clumps [2]. This species is a red alga capable of producing substantial amounts of carrageenan, a hydrocolloid widely used in the chemical industry [3]. The carrageenan extracted from Kappaphycus is predominantly κ-carrageenan, which is utilized in the food, cosmetic, pharmaceutical, and textile industries, as well as in aromatic diffuser products [4].

E. cottonii is extensively cultivated across the Asia–Pacific region, including Indonesia. Common farming techniques adopted by local seaweed farmers include the off-bottom method, the longline system, and raft culture. These methods rely heavily on surface area availability. The success of seaweed aquaculture is influenced by several key factors, such as seedstock selection (quality and characteristics of propagules), cultivation techniques (depth, planting distance, and seed weight), and appropriate site selection. Among these, planting depth plays a particularly important role, as it directly affects seaweed growth. According to [5], seaweed placed too deep in the water column is difficult to maintain, whereas shallow placement exposes it to excessive sunlight. Planting depth determines the degree of light penetration, which is essential for photosynthesis.

To date, only a few seaweed farmers have utilized the water column as a vertical growing space. Cultivation systems that make use of water depth are known as verticulture or multi-tiered rack systems. Verticulture offers several advantages, including greater resilience to fluctuations in water quality and more efficient use of farming areas [6]. [7] describe verticulture as a technique in which seaweed propagules are attached vertically along rows of lines arranged to exploit the water column within a defined depth range. This approach has the potential to minimize spatial constraints and increase overall production.

Previous research by [6] in Baruta Doda Bahari Village, Sangia Wambulu District, Central Buton Regency reported a net production of 3,211 kg per cycle per 10 × 10 m² using verticulture, compared to only 202 kg per cycle per 10 × 10 m² obtained using the longline method. These findings clearly demonstrate that verticulture yields significantly higher production than conventional longline farming. However, variations in planting depth within verticulture systems remain insufficiently explored. Therefore, the present study was conducted to examine the effects of different planting depths on the growth and productivity of *E. cottonii* cultivated using a verticulture system, with the ultimate goal of optimizing space utilization and enhancing production.

MATERIAL AND METHOD

Materials and Equipment

The materials used in this study included seawater, PVC pipes, and *Eucheuma cottonii* seedlings. The equipment comprised plastic baskets, netting, scissors, a mobile phone camera, brushes, rope, a weighing scale, a ruler, a drill, adhesive, a canoe, a lux meter, a refractometer, and a TDS meter.

Research Method

This study was conducted from June to September 2025 in the waters of Kodek Bay, North Lombok, Indonesia. An experimental approach was applied using a Completely Randomized Design (CRD) with four treatments and three replicates each, yielding a total of 12 experimental units. The treatments consisted of planting depths of 0 m (P0), 1 m (P1), 2 m (P2), and 3 m (P3).

Preparation of the Verticulture Frame and Cultivation Bags

The verticulture structure consisted of PVC pipes measuring 3 m in length and 1 m in width. Seaweed cultivation was carried out using cultivation bags. These bags were constructed from modified rectangular plastic baskets fitted with internal partitions and covered externally with netting of the same rectangular dimensions. The size of the cultivation bags matched the width of the verticulture frame, with one rectangular bag installed for each treatment (Fig 1).

Seedstock Preparation

The *E. cottonii* seedstock was sourced from the waters of Serewe Bay, East Lombok Regency. Only fresh, clean, and debris-free thalli were selected. Seedstock collection was conducted during low tide. Transport to the research site was carried out using a dry-transport method, in which the seedstock was placed inside insulated boxes to minimize moisture loss during transit. Upon arrival, the seedstock was acclimatized for seven days in the waters of Kodek Bay. After acclimatization, 30 g of seedlings were weighed for each treatment and placed into the verticulture containers by tying them securely at the designated depths according to the treatment design. Seedlings used in this study were green in color, firm to the touch, and exhibited thalli that did not break easily.

Maintenance and Monitoring

The cultivation period lasted 30 days, during which the thalli were monitored for growth and water quality. Growth assessments were conducted every 10 days, including measurements of weight, thallus length, thallus number, and survival rate. Water-quality monitoring was also performed every 10 days, covering temperature,

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pH, salinity, and light intensity. In addition, the netting surrounding the cultivation bags was regularly checked and cleaned to prevent fouling and ensure that sunlight could penetrate the culture media without obstruction.

Research Parameters

Absolute Growth

Absolute growth was calculated following [8]:

$$W = Wt - Wo$$

Where:

W : average absolute growth (g)

Wt : final seaweed biomass (g)

Wo : initial seaweed biomass (g)

Thallus Length and Thallus Number

Thallus length was measured using a ruler, while thallus number was determined manually by counting each thallus.

Specific Growth Rate (SGR)

Specific growth rate was calculated according to [9] as follows:

$$LPS = \frac{In\ Wt - In\ Wo}{t} x100\%$$

Where:

LPS : average specific growth rate (%/day)

Wt : final biomass (g)

W0 : initial biomass (g)

T : cultivation period

Survival Rate

Survival rate was measured using the formula from [8] :

$$SR = Nt/No \times 100$$

Where:

SR = survival rate (%)

Nt = number of surviving thalli at the end of the study

No = number of thalli at the beginning of the study

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Water-Quality Parameters

Temperature and pH were measured using a TDS meter, salinity was assessed with a refractometer, and light intensity was measured using a lux meter.

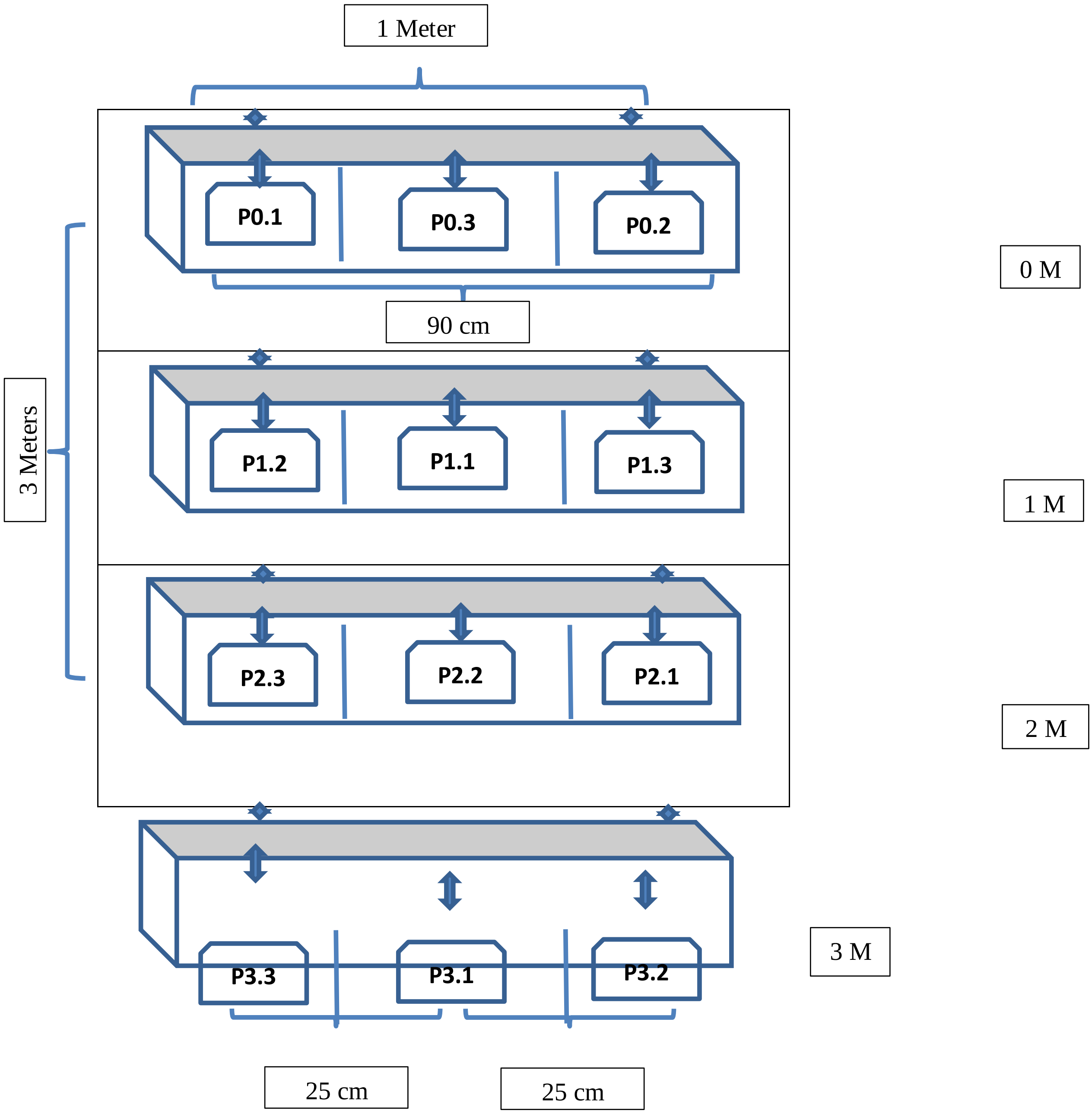

Fig 1. Verticulture Design for Seaweed Cultivation

Description: RL (Seaweed), straight blue lines (Riser Lines), 25 cm (Planting Distance), 3 m (Verticulture Pipe Length), 1 m (Pipe Width), and 90 cm (Bag Length).

Data Analysis

The collected data were analyzed using analysis of variance (ANOVA) in SPSS to determine the effects of each treatment. When significant differences were detected, Duncan's multiple-range test was used as a post hoc analysis. Water-quality parameters were analyzed descriptively. The results were then presented as histogram graphs generated in Microsoft Excel.

RESULTS

The present study demonstrates that varying planting depths significantly affected the growth performance of *E. cottonii* cultured in a verticulture system over the 30-day cultivation period (Table 2).

Table 1. The influence of varying planting depths on the growth performance of *Eucheuma cottonii* cultivated in a verticulture system

Depht	Parameters						
	Absolute weight (g)	Thallus Length (cm)			Thallus Number	Spesific Growth Rate	Survival Rate
		10 days	20 days	30 days			
P0 (0 m)	29.29±2.14^{C}	0,6±0.10^{b}	0,9±0.06^{b}	1,1±0.12^{c}	67,3±1.53^{c}	2,27±0.12^{c}	88,9±0.58^{c}
P1 (1 m)	20,92±1.68^{b}	0,5±0.06^{ab}	0,7±0.15^{ab}	0,9±0.06^{b}	59,7±1.53^{b}	1,76±0.11^{b}	66,7±0.00^{bc}
P2 (2 m)	16,00±4.51^{b}	0,4±0.10^{a}	0,6±0.12^{a}	0,9±0.06^{ab}	53,7±1.53^{a}	1,41±0.33^{b}	44,4±0.58^{ab}
P3 (3 m)	7,08±1.61^{a}	0,4±0.10^{a}	0,5±0.10^{a}	0,7±0.06^{a}	53,0±2.65^{a}	0,70±0.15^{a}	33,3±0.00^{a}

Absolute Weight

The results showed that the average absolute weight gain of *E. cottonii* cultivated using the verticulture system at different depths ranged from 7 g to 29 g. The highest average absolute weight was recorded at the 0-m treatment (P0), with a value of 29 g, whereas the lowest was observed at the 3-m depth (P3), with an average weight of 7 g (Fig 2).

The analysis of variance (ANOVA) revealed that the verticulture method with varying cultivation depths produced significant differences ($p < 0.05$) in the absolute weight of *E. cottonii*. Duncan's post hoc test further indicated that the highest absolute weight was observed at the 0-m depth (P0), which differed significantly from all other treatments

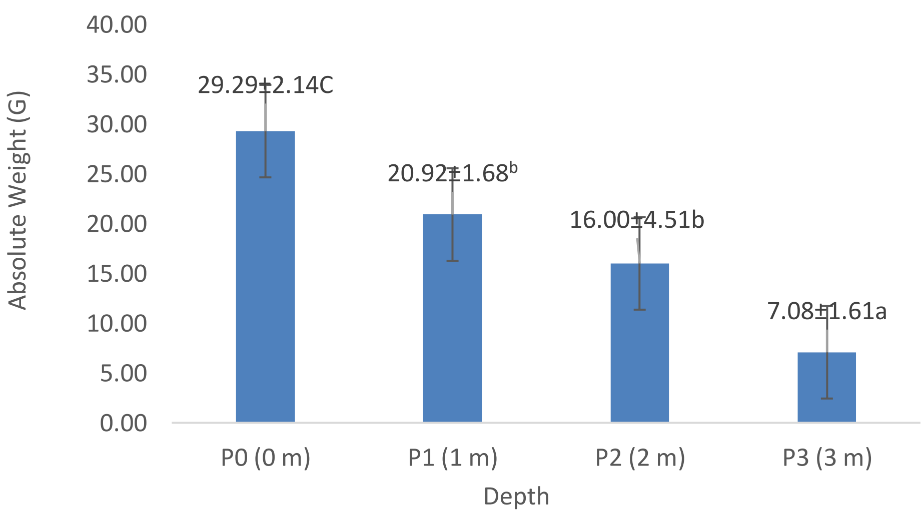

Fig 2. Average Absolute Weight of *E. Cottonii*

Thallus Length

The results showed that the average thallus length of *E. cottonii* cultivated under different verticulture depths ranged from 0.4 to 0.6 cm on day 10, from 0.5 to 0.9 cm on day 20, and from 0.7 to 1.1 cm on day 30. The

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highest average thallus length at all observation periods was recorded in the 0-m treatment (P0), whereas the lowest values were consistently found at the 3-m depth (P3) (Fig 3).

The analysis of variance (ANOVA) showed that the verticulture method with different cultivation depths produced significant differences ($p < 0.05$) in thallus length at all observation periods. Duncan's post hoc test indicated that the highest thallus length was consistently observed at the 0-m depth (P0), which differed significantly from all other treatments

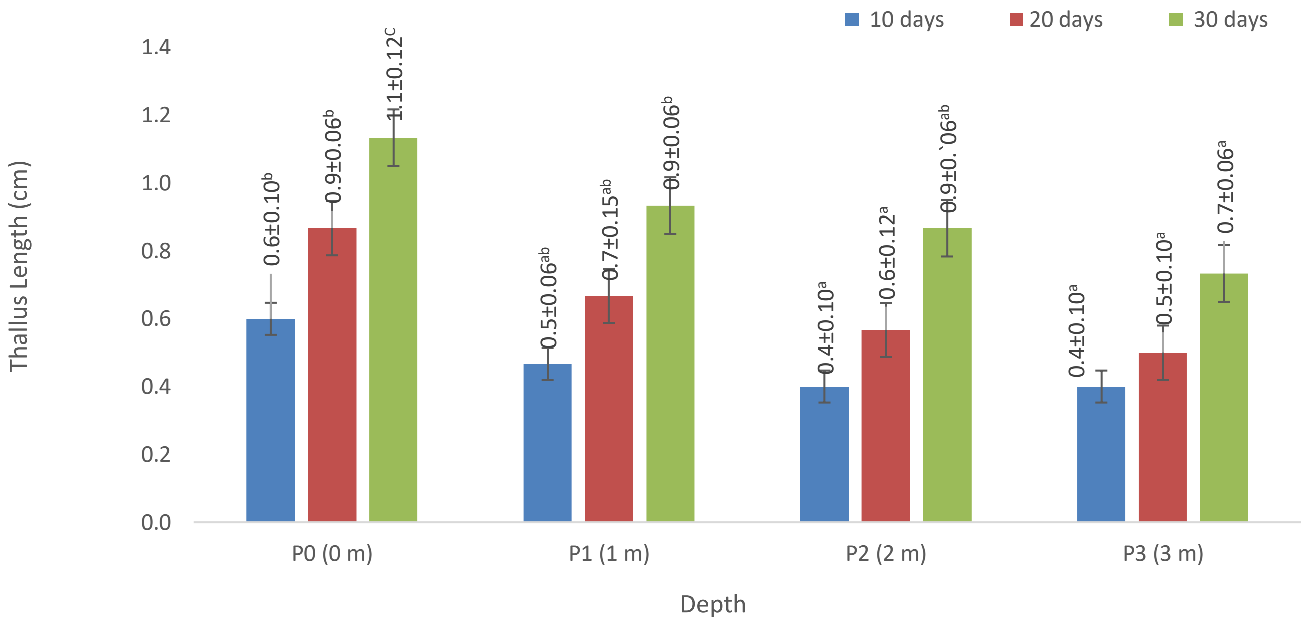

Fig 3. Average Thallus Length of *E. Cottonii*

Thallus Number

The results demonstrated that the average number of thalli produced by *E. cottonii* cultivated at different depths ranged from 53 to 67. The highest average number of thalli was recorded at the 0-m treatment (P0), with 67 thalli, whereas the lowest number was found at the 3-m depth (P3), with 53 thalli (Fig 4).

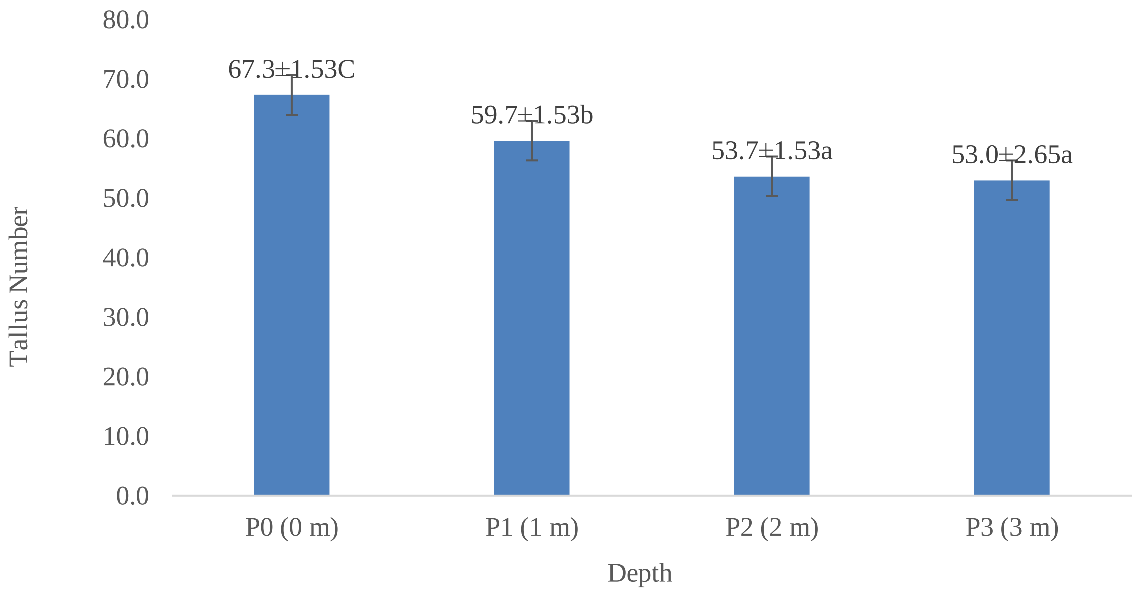

Fig 4. Average Number of Thalli of *E. cottonii*

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The analysis of variance (ANOVA) indicated that the verticulture method with different cultivation depths produced significant differences ($p < 0.05$) in thallus number. Duncan's post hoc test showed that the highest thallus number occurred at the 0-m depth (P0), which differed significantly from all other treatments.

Specific Growth Rate

The results showed that the average specific growth rate (SGR) of *E. cottonii* cultivated at different depths in the verticulture system ranged from 0.70% per day to 2.27% per day. The highest average SGR was recorded at the 0-m treatment (P0), with a value of 2.27% per day, whereas the lowest SGR occurred at the 3-m depth (P3), with a value of 0.70% per day (Fig 5).

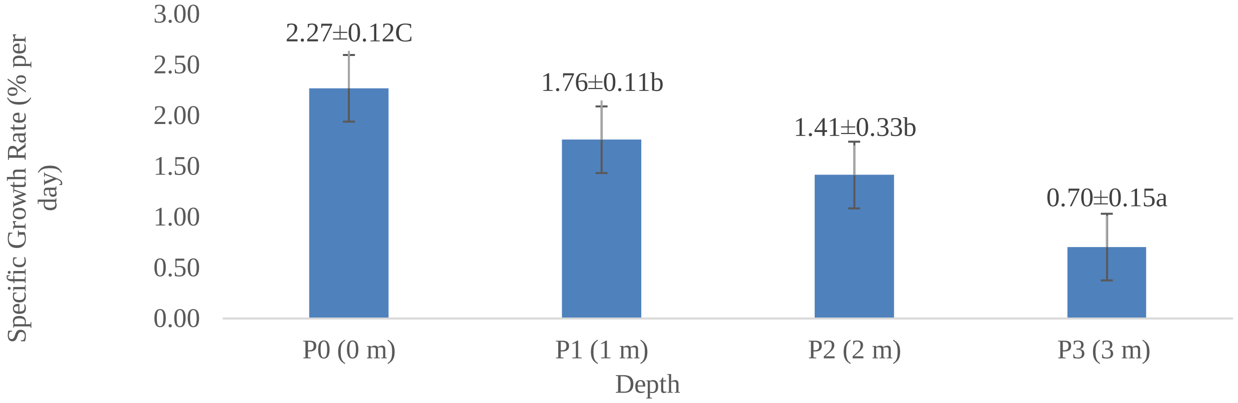

Fig 5. Average Specific Growth Rate of *E. cottonii*

The analysis of variance (ANOVA) showed that the verticulture method with varying cultivation depths produced significant differences ($p < 0.05$) in the specific growth rate of *E. cottonii.* Duncan's post hoc test indicated that the highest specific growth rate occurred at the 0-m depth (P0), which differed significantly from all other treatments.

Survival Rate

The results indicated that the average survival rate of *E. cottonii* cultivated at different depths in the verticulture system ranged from 33.3% to 88.9%. The highest survival rate was recorded at the 0-m treatment (P0), with a value of 88.9%, whereas the lowest survival rate occurred at the 3-m depth (P3), with a value of 33.3% (Fig 6).

The analysis of variance (ANOVA) indicated that the verticulture method with different cultivation depths produced significant differences ($p < 0.05$) in *E. cottonii* survival rate. Duncan's post hoc test showed that the highest survival rate occurred at the 0-m depth (P0), which was not significantly different from the 1-m depth (P1), but differed significantly from the 2-m (P2) and 3-m (P3) treatments.

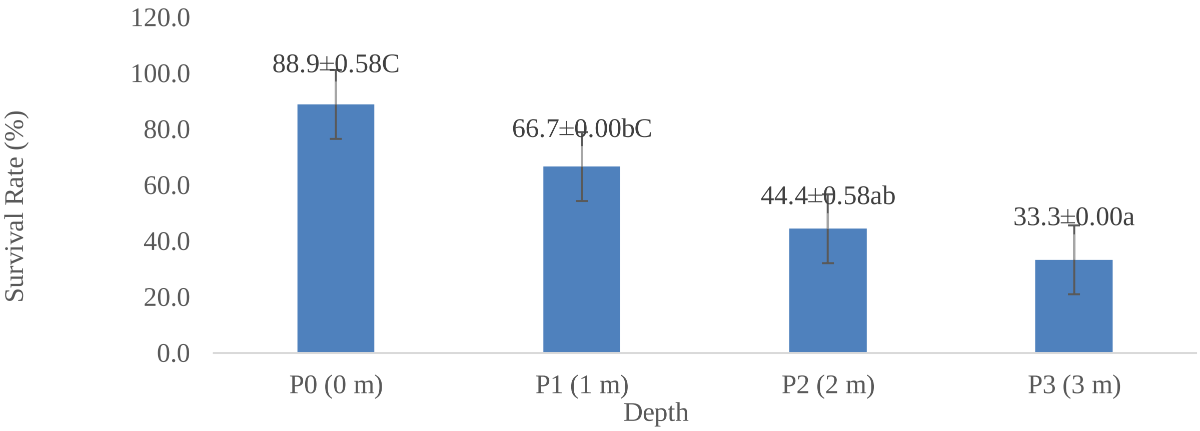

Fig 6. Average Survival Rate of *E. cottonii*

Water Quality

The water-quality measurements recorded throughout the culture period are presented in Table 2. The results indicate that all parameters remained within optimal ranges for *E. cottonii* growth (Table 2).

Table 1. Water-Quality Observation Data

Parameters	Value	Ideal	Reference
Temperature	27.90℃-28.1℃	26℃-29℃.	[10]
pH	8.06-8.07	6.8-9.6	[11]
Light Intensity	3.061-5.607	±5000 Lux	[12]
Salinity	34-35	15-35 ppt	[10]

DISCUSSION

Seaweed growth is influenced by a combination of intrinsic and extrinsic factors. Intrinsic factors include species characteristics, seed quality, and thallus properties, whereas extrinsic factors pertain to environmental and habitat conditions. As noted by [12], differences in seaweed growth are shaped by the interaction of these internal and external variables. While intrinsic factors determine the biological potential of the seaweed, extrinsic factors—such as the physical and chemical properties of the surrounding water—modulate the actual growth performance.

The present study demonstrates that cultivating *E cottonii* using the verticulture method at varying depths over a 30-day cultivation period significantly affected absolute weight, specific growth rate, thallus length, thallus number, and survival rate (Table 1.). Overall, the verticulture method at 0 m (P0) was the most effective, resulting in higher growth and better survival than at other depths. Seedlings positioned closer to the water surface exhibited higher growth rates. The highest absolute weight of *E. cottonii* was observed at 0 m depth (P0), reaching 29.29±2.14 g (Fig 2). Light availability plays a critical role in seaweed growth through photosynthesis. The shallow 0 m depth provides higher light intensity, which supports optimal growth. [13] noted that extremely low light intensities result in slow growth due to incomplete photosynthesis. Similarly, [14] emphasized that seaweed growth is highly dependent on sunlight, as photosynthesis enables nutrient absorption and stimulates daily growth through cell division.

As cultivation depth increases, the absolute weight of *E. cottonii* decreases, primarily due to reduced photosynthesis and lower oxygen circulation at deeper depths. Depth is closely associated with water clarity and light penetration, which determine the amount of sunlight reaching different water layers [15]. [15] further reported that seaweed requires sunlight for photosynthesis, which in turn drives thallus proliferation; as a result, both the size and number of thalli increase over time. The absolute weight of seaweed in this study was lower than that reported by [16], who observed an absolute growth of 127 g for *K. alvarezii* after 45 days of verticulture, starting from an initial weight of 100 g at the same depth as the present study. This discrepancy is likely due to differences in cultivation sites. The waters of Kodek Bay used in this study are less frequently used for seaweed farming compared to Nain Island, the site of the previous research.

Cultivation of *E. cottonii* using verticulture at 0 m depth (P0) also resulted in greater thallus length and higher thallus numbers in this study, measuring 1.1±0.12 cm (Fig 3) and 67±1.53 thalli (Fig 4), respectively. This enhanced growth is likely associated with the shallower depth of the P0 treatment compared to other depths. Although light intensity at 0 m is sufficiently high to support photosynthesis, it is not excessive, minimizing the risk of stress from solar radiation or elevated temperatures. Furthermore, water currents at this depth tend to be more stable and carry nutrients essential for seaweed growth. [17] highlighted that water currents play a crucial role in transporting nutrients, which serve as food reserves for optimal seaweed growth. Currents also facilitate the delivery of oxygen and the removal of metabolic waste, allowing thalli to absorb nutrients more efficiently and produce higher-quality biomass—thicker, fresher, and less prone to epiphytic colonization.

The thallus length of E. cottonii observed in this study was lower than reported in some previous studies. [18] reported a thallus length of 17.70 cm for *K. alvarezii* cultivated using a floating raft method at the same depth. The higher thallus length in that study is likely due to a longer cultivation period of 45 days.

Similarly, the highest specific growth rate (SGR) of *E. cottonii* was observed at 0 m depth (P0), reaching 2.27±0.12% per day, which is considered favorable. [19] suggested that a daily growth rate exceeding 2% is suitable for seaweed cultivation, while [20] considered an SGR greater than 3% per day as economically advantageous. SGR reflects the daily growth capacity of *E. cottonii*, and the values obtained in this study are consistent with those reported by [21], who found an SGR of 2.83% per day for *E. cottonii* cultivated using the long-line method at similar depths and planting distances. Depth is a key factor influencing growth, as increased depth reduces light penetration and oxygen circulation [22].

The superior growth of *E. cottonii* at 0 m depth in this study was also supported by a high survival rate of 88.9±0.58%. This is likely due to increased nutrient availability, particularly nitrate (NO_3^-) and phosphate (PO_4^{3-}), which are critical for survival. Seaweed requires adequate and balanced nutrient levels to achieve optimal growth and production [23]. Consequently, nutrient sufficiency is a significant factor contributing to the high survival rates observed. Although slightly lower than the 92.59% survival rate reported by [24] for *E. cottonii* cultivated with the long-line method at similar planting distances, the survival rate in this study is still considered excellent.

Water quality measurements throughout this study remained within optimal ranges to support the growth of *E. cottonii* (Table 1). This indicates that differences in growth and survival rates observed in the study were primarily influenced by depth treatments rather than water quality. [14] stated that monitoring water quality in research is essential to determine the tolerable range for seaweed, thereby ensuring its growth and survival. The parameters measured in this study included temperature, pH, light intensity, and salinity.

Water temperature during the study ranged from 27.9°C to 28.10°C, which is considered optimal for seaweed cultivation. Temperature is a key physical parameter influencing photosynthesis, as optimal temperature correlates with sunlight availability. This aligns with [10], who reported that the optimal temperature range for E. cottonii growth is 26°C to 29°C.

pH, or the acidity level of the water, is another critical factor affecting the survival of aquatic organisms, as extreme pH values can indicate poor water conditions. During this study, pH ranged from 8.06 to 8.07, which falls within the optimal range for *E. cottonii* growth. This is supported by [11], who reported that pH values between 6.8 and 9.6 are suitable for *E. cottonii*.

Light intensity measured during the study ranged from 3,061 to 5,607 lux. Light intensity is a limiting factor in photosynthesis, and higher intensities accelerate photosynthetic activity, ultimately increasing wet biomass. The values obtained in this study are considered optimal for seaweed cultivation. [12] suggested that an ideal light intensity for seaweed cultivation is approximately 5,000 lux. Light intensity is strongly influenced by water depth, with deeper waters receiving less light.

Salinity during the study ranged from 34 to 35 ppt, representing the concentration of salts in the water. These values are within the optimal range for seaweed cultivation. [11] reported that salinity levels between 15 and 35 ppt are suitable for seaweed growth.

CONCLUSION

The study successfully evaluated the effect of planting depth on the growth performance of *E. cottonii* cultured using a verticulture system. The research concludes that the 0-meter depth (water surface) is the most optimal planting position for *E. cottonii* cultivation using the verticulture system in Kodek Bay, yielding superior growth and survival compared to 1, 2, and 3 meters. This condition is likely due to the maximal light intensity at the surface (3,061–5,607$ lux) supporting optimal algal photosynthesis. The application of the verticulture system with optimal utilization of the surface tier (0 m) has significant implications for scaling up seaweed cultivation in Indonesia and similar tropical regions. This system offers a viable solution to overcome horizontal land limitations and increase productivity per unit area, while promoting more efficient and sustainable farming practices by focusing on the most productive surface zone. Future research should explore the structural design and cost-effectiveness of scaled-up verticulture units in different coastal environments.

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