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The Determining Success of Polyculture *Caulerpa* sp and *Litopenaeus vannamei* using AHP Analysis

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***Abstract*— The Polyculture *Caulerpa* sp and *Litopenaeus vannamei* can reduce the risk of ecological impacts, increase shrimp growth, survival, production, increase shrimp resistance to disease, and maintain optimal water quality. *Analytical Hierarchy Process* (AHP) begins by determining the priority between water quality, growth rate, and harvest yields as more optimal parameters for the success of a polyculture. The measure of success is determined based on the results of expert assessments of polyculture and cultivation that produce more optimal water quality (temperature, pH, brightness, salinity, and dissolved oxygen), growth rates, and harvest yields. The results of the overall AHP analysis, which determined the success of *Caulerpa* sp and *Litopenaeus vannamei* polyculture based on expert assessments, showed a good level of consistency. The results show that water quality is a priority parameter in the success of *Caulerpa* sp and *Litopenaeus vannamei* polyculture with a weight of 0.597, followed by a growth rate of 0.297 and a harvest yield of 0.106. The analysis of priority water quality indicators for the success of polyculture is dissolved oxygen with a weight of 0.514, followed by pH of 0.246, salinity of 0.119, temperature of 0.079, and brightness of 0.042. Based on the results of experts of the combined weight comparison, polyculture is more optimal than cultivation, with a considerable comparison weight of 0.678 and 0.322, measuring the success of *Caulerpa* sp and *Litopenaeus vannamei* polyculture.**

Keywords— Polyculture, *Caulerpa* sp, *Litopenaeus vannamei*, Analytical Hierarchy Process (AHP)

I. INTRODUCTION

Litopenaeus vannamei cultivation in Asia is superior to shrimp, with rapid growth, high salinity tolerance, and tolerance to poor environmental conditions [1]. However, intensive shrimp ponds have high stocking densities (70–150 m^2 of shrimp) [2], resulting in excessive release of nutrients in nitrogen and phosphorus compounds in the cultivation system and decreased water quality. It causes hypoxia and eutrophication and is susceptible to disease, which causes reduced shrimp production [3][4][5]. To reduce the negative impacts caused by cultivation waste, the approach with polyculture techniques with species at different trophic levels as an environmentally friendly approach to the sustainable development of the fisheries cultivation sector, especially the shrimp industry [6][7][8][9]. Using polyculture techniques with seaweed integration with shrimp can reduce the risk of ecological impacts, increase shrimp growth, survival, production, increase shrimp resistance to disease, and maintain optimal water quality [10][11]. One type of seaweed with substantial economic value and a business opportunity is *Caulerpa* sp. It is one of the leading commodities and can potentially be a functional food because it is known as a source of dietary fibre and can be used as a functional food to prevent obesity and degenerative diseases [12]. *Caulerpa* sp. contains antioxidants, folic acid, carbohydrates, protein, fat, vitamins, and other minerals. Seeing the potential of *Caulerpa* sp can integrate with *Litopenaeus vannamei* use of his technology with polyculture. These commodities are included in critical economic values , so they have a high potential to increase business opportunities. The problems that occur in Indonesian seaweed farmers are still relatively less prosperous. The comparison of seaweed harvest results with shrimp is 1 ton of shrimp equals 100 tons of seaweed. As a result of the low selling value of wet and dry seaweed raw materials, seaweed productivity decreases. The operational costs for seaweed cultivation are not comparable to the harvest results. It indeed results in a decrease in community income, especially for seaweed farmers, due to low selling prices and minimal marketing of seaweed in Indonesia. Seaweed, especially sea grapes, has a high potential to be explored and utilized in processed foods, medicines, and other products. Based on the problems, the strategy for sustainable cultivation of *Caulerpa* sp integrated with *Litopenaeus vannamei*

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with polyculture models creates new business ideas, especially for farmers or industries with higher yields. Polyculture research using *Caulerpa* sp. integrated with *Litopenaeus vannamei* can increase production results and feed efficiency, which is relatively better [13]. Other research uses a combination of *Caulerpa* sp. with *Litopenaeus vannamei* is effective as a biofilter to improve water quality and the growth performance of vannamei shrimp. Using *Caulerpa* sp. as a biofilter can maintain water quality, reduce ammonia concentration, and increase growth rate [14]. [15] Seaweed should be added to L. vannamei feed as an alternative nutrition, where seaweed is rich in important minerals that are considered additional natural nutrients and can replace the use of antibiotics in shrimp and fish. *Caulerpa* sp. is known to have antibacterial and immunostimulant activity [16]. *Caulerpa* sp. is expected to be a low-cost source of nutrients that can reduce feed costs and increase growth and survival [17]. Based on research related to polyculture, using *Caulerpa* sp. and *Litopenaeus vannamei* present innovative sustainable solutions in developing aspects of fisheries cultivation, especially in Central Tapanuli Regency. Using environmentally friendly polyculture techniques will promise business opportunities for shrimp farmers or the shrimp industry. In the study, observations were made using AHP analysis methods to see the success of polyculture models. The parameters observed were water quality, growth rate, and harvest yields, which were used to optimize polyculture success. The novelty of this study compared to previous studies is the decision-making system to see the success of polyculture using *Caulerpa* sp. and *Litopenaeus vannamei* in Central Tapanuli Regency using the *Analytical Hierarchy Process* (AHP). AHP method makes it easier to determine the weight value of the criteria used in water quality, growth rate, and harvest yields in the success of polyculture. Then, the AHP method is a decision-making process involving related parties such as local governments, fishermen, shrimp farmers, and academics related to aquaculture. It will later become a policy recommendation to the local government related to economic benefits. This polyculture technique using *Caulerpa* sp. and *Litopenaeus vannamei* has never been carried out in Central Tapanuli Regency, and knowledge about sea grapes is still minimal by coastal communities and the local government. Even the community is unfamiliar with the potential and business opportunities using polyculture techniques. This research, of course, will increase the knowledge and skills of the community to make processed sea grapes, such as food products that can be used as typical products or souvenirs from Central Tapanuli Regency.

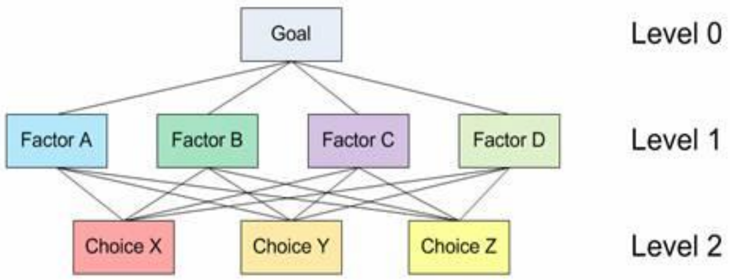

Figure 1. Structure AHP Analysis

II. Method

A. Research Procedure

This study uses a qualitative method. The qualitative research used is the *Analytical Hierarchy Process* (AHP) to determine policy recommendations that can be applied to the sustainability of the development of polyculture technology based on the results of interviews with 3 expert respondents from the Regional Government, Lecturers with a minimum work period of 3 years, and fishermen who understand and are experienced in the field of shrimp and seaweed cultivation.

The decision-making process is choosing an alternative. The main tool of AHP is a functional hierarchy with the main input of human perception. The existence of a hierarchy allows complex or unstructured problems to be broken down into sub-problems and then arranged into a hierarchy. AHP has the advantage of explaining the decision-making process as it can be depicted graphically so that all parties involved in the decision-making process understand it. According to [18], in solving problems, AHP has several principles that must be understood, including:

1. Creating a Hierarchy
   Complex system can be understood by breaking it down into supporting elements, hierarchically arranging and combining or synthesizing elements (Figure 1).

2. The assessment of criteria and alternative criteria is done by pairwise comparison. For various problems, 1 to 9 is the best scale for expressing opinions. Table can measure the value and definition of qualitative opinions from the comparison scale (Table 1).

TABLE 1.
SCALE OF RELATIVE IMPORTANCE *ANALYTIC HIERARCHY PROCESS* (AHP)

Scale of importance	Definition
1	Equally Important
3	Weak Importance
5	Strong Importance
7	Demonstrated Importance
9	Absolute Importance
2,4,6,8	Intermediate Importance

Source: Saaty dan Thomas (1990)

3. Synthesis of Priority (determining priorities) for each criterion and alternative. This requires a pairwise comparison. The relative comparison values of all alternative criteria can be adjusted according to the predetermined judgment to produce weights and priorities. Weights and priorities are calculated by manipulating matrices or by solving mathematical equations.
4. Logical Consistency has 2 meanings. First, similar objects can be grouped according to uniformity and relevance. Second, it concerns the level of relationship between objects based on certain criteria.

B. *Analytical Hierarchy Process (AHP)*

The procedures or steps in the AHP method [18] include:

1. Defining the problem and determining the desired solution, then compiling a hierarchy of the issues faced. Compiling a hierarchy is done by setting the goals that are the targets of the system at the top level.
2. Determining Element Priorities
   a. The first step in determining element priorities is to make a pairwise comparison, namely comparing elements in pairs according to the given criteria.
   b. The pairwise comparison matrix is filled using numbers to represent the relative importance of one element to another.
3. Synthesis
   Considerations of pairwise comparisons are synthesized to obtain the overall priority. Things done in this step are
   a. Adding the values of each column of the matrix.
   b. Dividing each value of the column by the relevant column's total to obtain the matrix's normalization.
   c. Add the values of each row and divide by the number of elements to obtain the average.
4. Measuring consistency in decision-making, it is important to know how good consistency is because decisions based on low-consistent considerations are not desired. Things done in this step are
   a. Each value in the first column is multiplied by the relative priority of the first element, the value in the second column by the relative priority of the second element, and so on.
   b. Adding each row
   c. The result of the row summation is divided by the relevant relative priority element.
   d. Add the above quotient with the number of elements, the result is called the maximum Lambda (λ_{max})
5. Calculate the *Consistency Index* (CI) with the formula:
$$CI = \frac{\lambda_{max} - n}{n - 1}$$
   Where:
   n = number of elements
6. Calculate the *Consistency Ratio* (CR) with the formula:
$$CR = \frac{CI}{RI}$$
   Where:
   CR = Consistency Ratio, CI = Consistency Index, IR = Random Consistency Index
7. Check the consistency of the hierarchy. The data judgment assessment must be improved if the value exceeds 10% (0.1). However, the calculation results can be declared correct if the consistency ratio (CI/CR) is less than or equal to 10% (0.1).

For this research to be more focused on following the objectives, the flow arranged for implementation is as follows:

1. Literature study of the AHP method by analyzing the AHP method as a decision support system model.
2. Interviews in implementing the AHP method as a decision support system model.
3. Implement the AHP method in a decision-making process related to cultivation with polyculture techniques based on shrimp and sea grapes.
4. Evaluating the application of the AHP method in a decision-making support system for cultivation with polyculture techniques based on shrimp alongside sea grapes to produce optimal decisions.

III. RESULTS AND DISCUSSION

A. AHP Analysis of Determining the Success of *Caulerpa sp.* and *Litopenaeus vannamei* Polyculture.

The success of *Caulerpa* sp. and *Litopenaeus vannamei* polyculture is determined based on the results of water quality measurements, growth rates, and more optimal harvest results compared to *Litopenaeus vannamei* cultivation according to expert assessments using the AHP method. The analysis begins by determining the priority between water quality, growth rate, and harvesting results as more optimal parameters in the success of a polyculture, where optimal water quality parameters consist of indicators of temperature, pH, brightness, salinity, and dissolved oxygen. Furthermore, the measure of success is determined based on the results of expert assessments of polyculture and cultivation that produce more optimal water quality (temperature, pH, brightness, salinity, and dissolved oxygen), growth rates, and harvest results. The following figure 2 results from the overall AHP analysis of the success of *Caulerpa* sp. and *Litopenaeus vannamei* polyculture based on expert assessments that show good consistency. The CR (*consistency ratio*) value ranges from 0.00 to 0.0675 (Figure 2) for optimal parameter priorities and optimal water quality indicators, as well as a λ_{max} value that is close to or equal to 2 (the number of polycultures compared) for more optimal polyculture and cultivation determination priorities.

Seeing the chance of success of polyculture by 68% using AHP analysis, *Caulerpa* sp and *Litopenaeus vannamei* polyculture can be utilized for farmers or aquaculture entrepreneurs, especially Vannamei shrimp in Central Tapanuli Regency. Based on the priority of determining the success of optimal parameters, namely water quality. Previous research related to *Caulerpa* sp. confirmed that it could improve water quality and increase the resistance of farmed shrimp [19]. Stated that there are rarely any disease attacks on shrimp or fish in polyculture ponds that use seaweed as a biofilter. The quality of pond or pond water is a crucial factor in determining shrimp growth, and poor quality can inhibit growth and even cause death in shrimp [20]. The polyculture system is one solution to prevent decreased water quality and the environment. Water quality is an essential factor in determining cultivation growth, and poor quality can inhibit growth and even cause death in cultivation results. Applying the polyculture system provides more significant benefits and lower costs than the monoculture cultivation system. This polyculture is a cultivation system that supports achieving the blue economy concept and sustainable development goals, which the Government of the Republic of Indonesia is promoting.

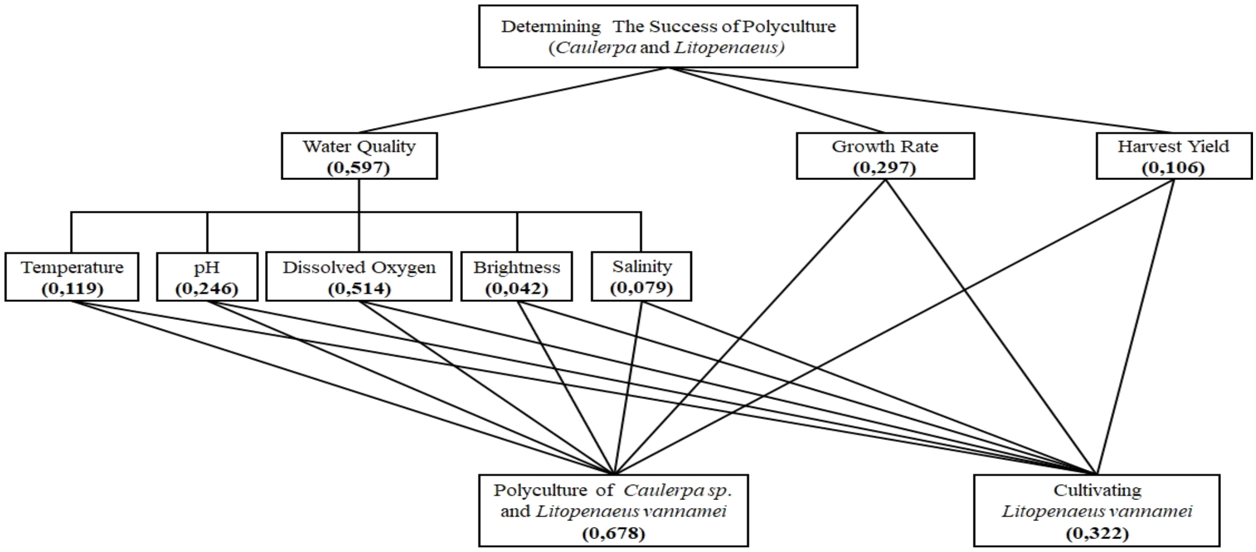

Figure 2. The determining success of *Caulerpa* sp. and *Litopenaeus vannamei* using AHP analysis

TABLE 2.
OPTIMAL PARAMETERS PRIORITY FOR THE SUCCESS OF POLYCULTURE (*Caulerpa sp.* and *Litopenaeus vannamei*)

Parameters	Water Quality	Growth Rate	Harvesting	Weight
Water Quality	1	2,621	4,309	0,597
Growth Rate	0,382	1	3,634	0,297
Harvesting	0,232	0,275	1	0,106

CR = 0,0591

B. Analysis Optimal Priority Parameters for the Success of Polyculture *Caulerpa sp* and *Litopenaeus vannamei*

The following table presents the optimal parameter priority weights for the success of *Caulerpa* sp. and *Litopenaeus vannamei* polyculture based on a pairwise comparison of geometric means between water quality, growth rate, and harvest yields according to three experts. The results show that, according to experts, water quality is the most optimal parameter for the success of *Caulerpa* sp. and *Litopenaeus vannamei* polyculture with a weight of 0.597, followed by a growth rate of 0.297 and a harvest yield of 0.106 (Table 2). The assessment results by experts show good consistency with a *consistency ratio* (CR) of 0.0591. Based on the results of the optimal priority analysis of the success of polyculture, water quality is the most critical indicator of the success of polyculture. It is in line with previous research that water quality is an essential factor in the sustainability of cultivation. Inappropriate water quality can interfere with the performance of vaname shrimp production and can cause potential cultivation failure [21].

C. *Water Quality Indicators Priorities Optimal for the Success Polyculture of Caulerpa sp and Litopenaeus vannamei.*

In this case, water quality parameters in determining the success of polyculture *Caulerpa* sp. and *Litopenaeus vannamei* are measured based indicators on temperature, pH, brightness, salinity and dissolved oxygen. The

TABLE 3.
WATER QUALITY OPTIMAL AS INDICATORS PRIORITIES FOR THE SUCCESS OF POLYCULTURE
(*Caulerpa* sp. and *Litopenaeus vannamei*)

Indikators	Salinity	pH	Brightness	Temperature	Dissolved Oxygen	Weights	Mix Weights
Salinity	1	0,382	3	2,289	0,215	0,119	0,071
pH	2,618	1	5,313	4,642	0,303	0,246	0,147
Brightness	0,333	0,188	1	0,255	0,143	0,042	0,025
Temperature	0,437	0,215	3,922	1	0,143	0,079	0,047
Dissolved Oxygen	4,651	3,3	6,993	6,993	1	0,514	0,307

CR = 0,0675

TABLE 4.
ANALYSIS OF DETERMINING THE SUCCESS OF POLYCULTURE (*Caulerpa* sp. and *Litopenaeus vannamei*)

Indikators	Polyculture	Cultivation	Weights	Mix Weights
Salinity[a]				**0.071**
Polyculture	1	1	0,5	0,0355
Cultivation	1	1	0,5	0,0355
pH[b]				**0,147**
Polyculture	1	1	0,5	0,0735
Cultivation	1	1	0,5	0,0735
Brightness[c]				**0,025**
Polyculture	1	2,621	0,724	0,0181
Cultivation	0,382	1	0,276	0,0069
Temperature[d]				**0,047**
Polyculture	1	1	0,5	0,0235
Cultivation	1	1	0,5	0,0235
Dissolved Oxygen[e]				**0,307**
Polyculture	1	2,621	0,724	0,222
Cultivation	0,382	1	0,276	0,085
Growth Rate[f]				**0,297**
Polyculture	1	2,621	0,724	0,228
Cultivation	0,382	1	0,276	0,069
Harvesting[g]				**0,106**
Polyculture	1	3,302	0,768	0,077
Cultivation	0,303	1	0,232	0,029
Total				**1**
Polyculture				**0,678**
Cultivation				**0,322**

Polyculture = *Caulerpa sp.* and *Litopenaeus vannamei*
Cultivation = *Litopenaeus vannamei*
[a,b,d] $\lambda_{maks} = 2$, [c,e,f] $\lambda_{maks} = 2{,}00061$, [g] $\lambda_{maks} = 2{,}00025$

following table presents the priority weights and combined weights of the optimal water quality indicator priorities in the success of polyculture *Caulerpa* sp. and *Litopenaeus vannamei* based on the results of pairwise comparison of geometric means between temperature, pH, brightness, salinity and dissolved oxygen according to 3 experts. The results show that according to experts, dissolved oxygen is the most optimal water quality indicator in the success of polyculture *Caulerpa* sp. and *Litopenaeus vannamei* with a weight of 0.514, followed by a pH of 0.246, a salinity of 0.119, a temperature of 0.079 and brightness of 0.042 (Table 3). The assessment results by experts/specialists showed good consistency with a *consistency ratio* (CR) of 0.0591. The combined weight is a partition of the water quality weight based on each indicator. This means that the weight of water quality in determining the success of polyculture *Caulerpa* sp. and *Litopenaeus vannamei*, which was originally 0.597, is partitioned into 0.307 dissolved oxygen, 0.147 pH, 0.071 salinity, 0.047 temperature, and 0.025 brightness (Table 3).

Based on the analysis results, dissolved oxygen is the optimal indicator of water quality because *Litopenaeus vannamei* is very susceptible to dissolved oxygen in water. If the dissolved oxygen content is low, it will affect the shrimp's density and the harvest. *Litopenaeus vannamei* is very sensitive to environmental changes, and the presence of *Caulerpa* sp. can help provide additional oxygen because it can produce oxygen and act as a biofilter in shrimp ponds. The second order for optimal water quality indicators is pH, according [22] related to shrimp cultivation of all the water quality parameters in ponds, it was detected that the pH parameter was the highest compared to other parameters. The pH concentration value is related to salinity, brightness, and temperature parameters. The pH value has a contrasting relationship with brightness, meaning that if the pond water gets darker, the pH value will be more alkaline [22].

D. Analysis of Determining the Success of Polyculture Caulerpa sp. and Litopenaeus vannamei Based on Optimal Parameters and Indicators.

Caulerpa sp and *Litopenaeus vannamei* polyculture can be successful when the results of water quality measurements are obtained. According to expert assessments, temperature, pH, brightness, salinity, dissolved oxygen, growth rate, and harvest yields are more optimal than *Litopenaeus vannamei* cultivation. The following table contains priority weights and combined priority weights that state polyculture or cultivation with more optimal temperature, pH, brightness, salinity, dissolved oxygen, growth rate, and harvest yield measurements based on the results of pairwise comparison geometric averages according to the three experts. Based on water quality indicators, the results of expert assessments show that brightness and Dissolved Oxygen in *Caulerpa* sp and *Litopenaeus vannamei* polycultures with a weight of 0.724 each, are stated to be more optimal than *Litopenaeus vannamei* cultivation, with a weight of 0.276. Meanwhile, according to experts, both polyculture and cultivation are the same based on pH, salinity, and temperature.

Furthermore, based on growth rate and harvest yield, experts state that *Caulerpa* sp and *Litopenaeus vannamei* polyculture are more optimal than *Litopenaeus vannamei* cultivation with respective weights of 0.724 compared to 0.276 and 0.768 compared to 0.232. The results of expert assessments show good consistency, as seen from the λmax value approaching or equal to 2 (the number of alternatives compared) [23]. The total combined weight is a measure that states how optimal polyculture and cultivation are. The results of expert assessments state that *Caulerpa* sp. and *Litopenaeus vannamei* polyculture are said to be more optimal than cultivation with a comparative weight of 0.678 and 0.322, as well as being a measure of the success of polyculture *Caulerpa* sp. and *Litopenaeus vannamei*. It presents innovative, sustainable solutions for developing aspects of fisheries cultivation, especially in Central Tapanuli Regency.

The existence of polyculture techniques reinforces it, a cultivation method that involves placing several species in one cultivation container with different eating habits, which aims to minimize interspecific competition and increase production profits [24]. Applying the polyculture system in cultivation activities aims to increase land and feed efficiency, minimize operational costs, and provide additional income for farmers [25]. As fisheries science develops, the concept of polyculture cultivation also develops. The birth of a cultivation system that integrates various fish and non-fish species with different trophic levels in one cultivation scope, or what is often known as *Integrated Multi Trophic Aquaculture*, is one step to building sustainable aquaculture and implementing the zero-waste concept by maximizing the use of waste as an energy source to increase the biomass of cultivated species. Caulerpa as a sessile organism that is cultured together with shrimp, is located at the bottom of the pond with a position that must maintain maximum nutrients and sunlight penetration for photosynthesis [26][27]. The correct planting position for Caulerpa is planting it at the bottom of the pond, which is cultured with shrimp [9]. With the integration of *Litopenaeus vannamei* and *Caulerpa* sp. cultivation, it is more profitable in economic and ecological aspects because it saves on land and feed efficiency, minimizes operational costs used, provides additional income for farmers because they get double harvests, has a minor impact on the environment, especially shrimp pond waste can be utilized by sea grapes for its growth, and helps prevent a decline in water and environmental quality and maintains sustainability for maximum harvest results.

IV. Conclusion

The success of *Caulerpa* sp. and *Litopenaeus vannamei* polyculture is determined based on water quality, growth rates, and harvest results according to expert assessments using the Analytical Hierarchy Process (AHP). Results show that water quality is a priority parameter in the success of *Caulerpa* sp. and *Litopenaeus vannamei* polyculture with a weight of

0.597, followed by a growth rate of 0.297 and a harvest result of 0.106. Analysis of the priority of water quality indicators for the success of polyculture is dissolved oxygen with a weight of 0.514, followed by pH of 0.246, salinity of 0.119, temperature of 0.079, and brightness of 0.042. Assessment results by experts show good consistency with a consistency ratio of 0.0591. According to experts, the final result of the combined weight comparison is that polyculture is more optimal than cultivation with a considerable comparison weight of 0.678 and 0.322, measures of the success of polyculture of *Caulerpa* sp. and *Litopenaeus vannamei*.

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