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Shrimp and Seaweed Polyculture System as A Sustainable Aquaculture Approach: A Literature Review

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ABSTRACT

The increase in shrimp production in Indonesia is driven by high global demand, which often leads to environmental problems, particularly the accumulation of organic waste from feed and feces, which can degrade water quality and trigger eutrophication. Polyculture systems offer a potential solution to improve efficiency and sustainability in aquaculture by utilizing the ecological niches of different organisms. This study aims to analyze the application of polyculture systems combining shrimp and seaweed, as well as their effects on water quality and production performance. The method used is a descriptive exploratory approach through the review of various scientific literature from national and international journals. The results indicate that the integration of seaweed such as *Gracilaria* sp. acts as a natural biofilter capable of absorbing nitrogen compounds, maintaining water quality stability, and suppressing pathogenic bacteria. In addition, this system enhances growth rate, survival rate, and feed efficiency of shrimp. Overall, polyculture not only increases productivity and economic benefits but also supports the environmental sustainability of coastal aquaculture systems.

***Keywords*:** Polyculture, shrimp, seaweed, water quality, IMTA, aquaculture

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1. INTRODUCTION

The Ministry of Marine Affairs and Fisheries reports that Indonesia's total shrimp exports have grown at an average rate of 4.61% per year through 2022. Vaname shrimp account for approximately 75% of total shrimp production and are one of Indonesia's flagship commodities [15]. High global demand has driven increased shrimp production through various applications in aquaculture systems. Problems arise when organic matter from feed and feces in aquaculture systems becomes organic waste and settles at the bottom of water bodies. This enriches the sediment, thereby increasing the risk of environmental eutrophication, which can trigger algal blooms and degrade water quality in public waters, this may also potentially hinder aquaculture activities [9]. Samidjan [22] state that shrimp mortality is significantly influenced by environmental factors or water quality. Polyculture systems represent an alternative and an evolution of monoculture systems that can enhance the sustainability of aquatic organism production by optimizing space and timing within the aquaculture system.

Polyculture is a method of raising two or more types of organisms in the same tank to make land use more efficient. Polyculture uses only one tank per cycle, which can increase land productivity by producing more than one commodity at harvest [6]. Furthermore, this polyculture system has evolved into Integrated Multi-Trophic Aquaculture (IMTA), a system that adopts natural concepts within the food chain by combining the cultivation of commodities at different trophic levels. Two or more types of commodities are used, one type of commodity utilizes the waste produced by other organisms as a nutrient source, thereby enabling nutrient recycling by cultivating other organisms of economic value [24]. Aquaculture systems must minimize negative impacts on the environment, thus, this system is used to optimize the space and time of cultivation units and serves as an alternative that can mitigate environmental issues. Furthermore, this system optimizes the water column. The integration of these commodities directly enhances the efficiency of water-space utilization and contributes to increased harvest yields through the diversification of cultivated commodities.

Seaweed is a commodity that can be combined with shrimp farming because it acts as a biofilter that absorbs ammonia compounds in the water and stimulates the growth of zooplankton, which serves as natural shrimp feed. Seaweed is capable of degrading organic matter to support its own growth, thereby reducing the accumulation of organic matter in the water. Seaweed also contains bioactive compounds with antibacterial properties, which can prevent the growth of bacteria that may harm shrimp [28].

This study aims to analyze the implementation of a shrimp-seaweed polyculture system based on various published research findings, as well as to demonstrate its impact on water quality and production performance in shrimp farming systems.

2. RESEARCH METHODOLOGY

This study employs an exploratory descriptive method. The descriptive method involves an analysis at the descriptive level, systematically analyzing and presenting data so that it can be more easily understood and interpreted. The exploratory method aims to uncover new facts. This descriptive-exploratory study aims to describe a variable, phenomenon, or condition as it is [1]. The study will review and analyze various studies related to the application of a polyculture system of shrimp and seaweed in aquaculture. This approach involves collecting, identifying, and analyzing information from various scientific sources obtained from national and international journals via Google Scholar and Elsevier.

3. RESULTS AND DISCUSSION

3.1. Polyculture System

A polyculture system is a farming method that combines more than one species within a single production unit with the aim of improving resource utilization efficiency and system productivity. Each organism has distinct functions and benefits, and, as a result, they complement one another in utilizing different nutrients [7]. Baedlowi [6] state that the composition of organisms within a polyculture system has a significant impact on growth and productivity.

Polyculture systems represent a technological advancement in agricultural systems applied to aquaculture to improve the utilization and efficiency of feed available within the cultivation medium. The primary focus is on the trophic levels and feeding habits of the cultivated organism species, with the aim of enhancing their growth and biomass while minimizing interspecific competition [29] [7].

Cahya [7] note that polyculture systems were first used during the Tang Dynasty in 618, involving the cultivation of various types of carp in a single aquaculture tank. The promising results of this development prompted Chinese immigrants to introduce the polyculture system to Korea and Japan, from where it spread to Southeast Asia, particularly Indonesia.

The polyculture system has evolved and transitioned into a more modern system. This system is known as Integrated Multi-Trophic Aquaculture (IMTA), which involves using two or more species from different trophic levels within a single aquaculture tank, where the waste from one organism is utilized by another [23].

3.2. Polyculture System

The fundamental basis of polyculture systems is the concept of ecological niches, in which each organism plays a distinct role and functions within the aquaculture system. Utilizing different ecological niches minimizes competition among organisms and fosters mutually beneficial interactions. In a polyculture system of shrimp and seaweed, there is a reciprocal relationship between organisms based on the nutrient cycle. Shrimp act as heterotrophic organisms that produce aquaculture waste in the form of uneaten feed, feces, and nitrogen compounds such as ammonia (NH_3), nitrite (NO_2^-), and nitrate (NO_3^-). In a monoculture system, this waste can degrade water quality. However, in a polyculture system, the waste is subsequently utilized by seaweed as an autotrophic organism.

Seaweed, such as *Gracilaria* sp., is capable of absorbing these inorganic nutrients for photosynthesis and growth, thereby functioning as a natural biofilter and helping to reduce waste concentrations in the water. This interaction creates a more efficient and stable system, as shrimp waste does not accumulate but is instead reused by seaweed. Thus, the relationship between shrimp and seaweed in polyculture systems is mutually complementary. Shrimp provide a source of nutrients for seaweed, while seaweed contributes to maintaining an environmental quality that supports shrimp growth [13]. The mechanism for implementing the shrimp and seaweed polyculture system is shown in Figure 1.

Seaweed uses its thallus to absorb various organic compounds, including ammonia, nitrate, and nitrite. These organic compounds are utilized to meet its nutritional needs, allowing seaweed to function as a biofilter. For example, *Gracilaria* sp. has the ability to absorb nitrogen from the water at a rate of 0.4 g nitrogen m^{-2} day^{-1} [4]. Additionally, water quality degradation caused by high concentrations of ammonia and total ammonia nitrogen (TAN) can lead to the proliferation of bacteria, such as Vibrio, in shrimp ponds. Thus, the presence of *Gracilaria* sp. in polyculture systems can suppress Vibrio bacteria. It is also known that *Gracilaria* sp. possesses antibacterial activity that can protect penaeid shrimp [20].

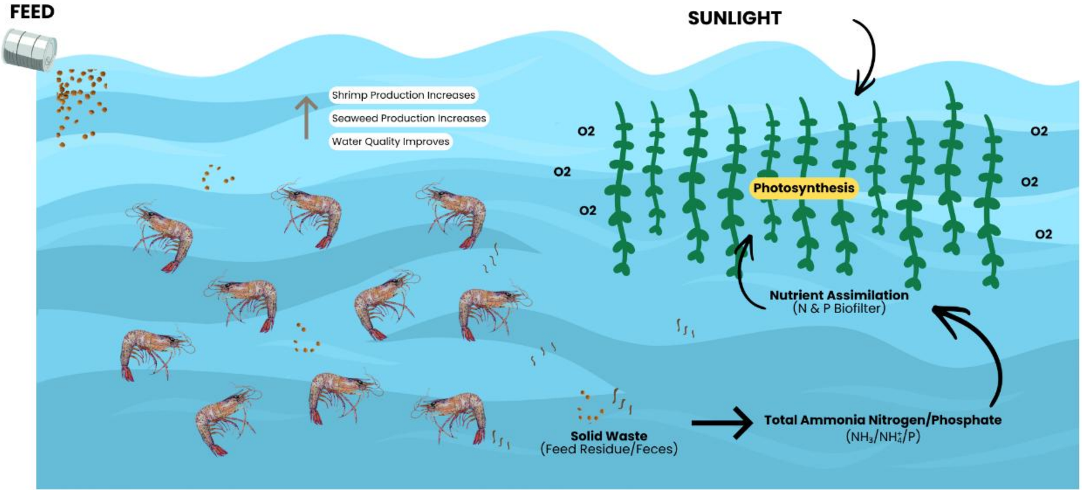

Figure 1. Schematic Representation of a Shrimp and Seaweed Polyculture System.

The polyculture/IMTA system is a highly flexible aquaculture system that can be applied in both freshwater and marine environments and can utilize various species combinations, such as shrimp/mussels, fish/shrimp/mussels, shrimp/seaweed, etc. [24]. The system's flexibility also allows it to be applied to various types of aquaculture systems; an example of shrimp polyculture with seaweed in the same system is shown in Figure 2. Figure 3 illustrates a polyculture system with IMTA development in separate systems, yet, the water systems remain integrated.

Figure 2. Shrimp-Seaweed Polyculture System
Sumber : Ly [12]

The application of shrimp polyculture systems integrated with seaweed continues to evolve through various research studies. The success of this system is determined by various parameters, such as the shrimp stocking density used, the biomass of seaweed introduced into the aquaculture system, and so on. The parameters determining the success of this aquaculture system vary significantly across the literature. Research by Samocha [23] found that excessively high seaweed density can trigger light competition and inhibit the specific growth rate of algae to below 2% per day. Increased organic matter from shrimp secretions can affect the reduction in Glacilaria biofiltration efficiency.

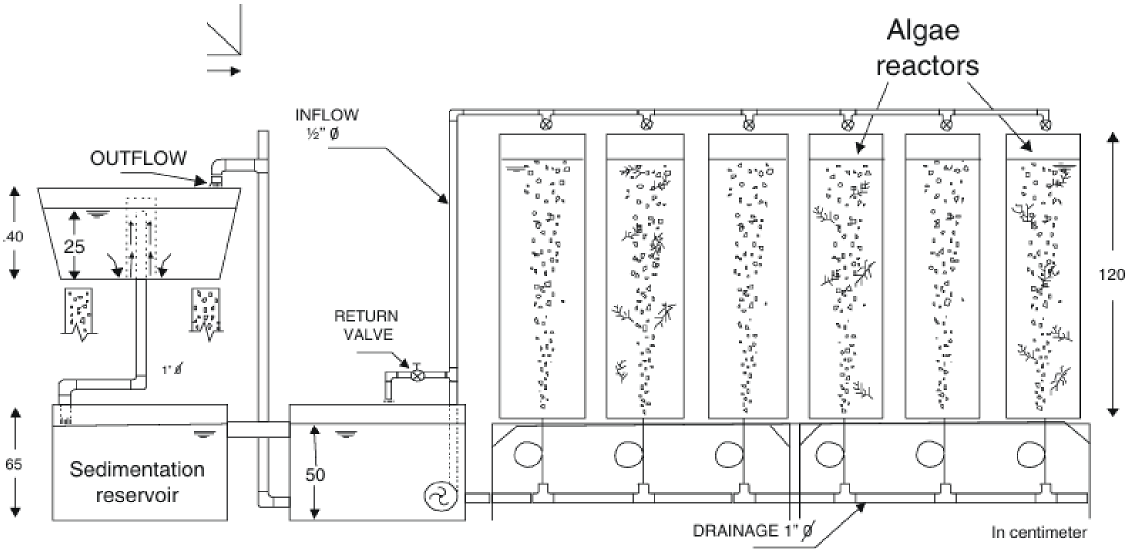

Figure 3. Polyculture System in the Form of IMTA Shrimp with Seaweed
Sumber : Robledo dan Freile [19]

From a technical perspective, parameters such as shrimp stocking density and seaweed biomass vary significantly across studies. For example, Tien [25] used shrimp densities of up to 500 individuals/m^3 with a seaweed biomass of 2 kg/m^3 and demonstrated that the system could still maintain water quality at certain densities.

Meanwhile, other studies show that a seaweed density of 3.125 g/L is optimal to support the performance of polyculture systems [11]. Environmental conditions such as salinity, temperature, and light are also key factors in the system's success. Seaweed requires sufficient light intensity for photosynthesis, thus, in systems with high turbidity, its growth can be inhibited, as reported by Henry-Silva [9]. This indicates that a key factor in this system is influenced by the achievement of a dynamic equilibrium between nitrogen-free waste from shrimp and the assimilation capacity of seaweed.

3.3. The Impact of Shrimp and Seaweed Polyculture Systems on Water Quality

Shrimp-seaweed polyculture systems play a crucial role as bioremediation agents by absorbing nitrogen waste produced from uneaten feed and shrimp metabolism. Seaweeds such as *Gracilaria verrucosa* are capable of assimilating nitrogen in the form of Total Ammonia Nitrogen (TAN) and Nitrite (NO_2), thereby keeping the concentration of these toxic substances below the threshold that is harmful to shrimp [11]. The addition of seaweed at a density of 2 kg/m³ has been shown to significantly maintain stable water quality even at high shrimp stocking densities of up to 300 individuals/m³ [25]. Additionally, the use of sea grapes (*Caulerpa lentillifera*) in intensive polyculture systems has also demonstrated high effectiveness in reducing orthophosphate and ammonia levels [2].

The presence of macroalgae in polyculture ponds has a positive effect on the stability of water physicochemical parameters, particularly in maintaining dissolved oxygen (DO) levels and pH. Seaweed contributes to increased dissolved oxygen levels through photosynthesis during the day, which is essential for shrimp respiration and growth [26]. Optimal seagrass planting distances, such as 45 cm, can improve water circulation and plankton abundance, supporting the balance of the pond ecosystem [21]. Additionally, polyculture systems help minimize fluctuations in water quality parameters caused by extreme weather changes, thereby creating a more controlled aquaculture environment [17].

The integration of various commodities (IMTA), such as shrimp, milkfish, and seaweed, creates synergies that lead to more efficient nutrient utilization compared to monoculture systems. Milkfish and red tilapia in polyculture systems act as natural cleaners that consume detritus and organic residues, thereby reducing the waste load in the water column [16]. Reducing the feed rate by up to 75% in IMTA systems does not degrade water quality, as a balanced ecosystem provides natural nutrients and maintains nutrient uptake efficiency [10]. This indicates that polyculture actively reduces the risk of eutrophication and the accumulation of organic matter on the pond bottom [11].

Ecologically, polyculture systems provide sustainable environmental protection, particularly in coastal areas vulnerable to external disturbances. Seaweed acts as a natural biofilter that enhances the carrying capacity of ponds, especially in areas affected by erosion or tidal flooding [14]. The stability of water quality maintained by this biofilter directly correlates with an increase in shrimp survival rates to over 80% [12]. Thus, the polyculture approach not only maintains water quality on a local scale but also supports the broader sustainability of coastal ecosystems [5]. The impact of the vanamei shrimp and seaweed polyculture system on water quality is shown in Table 1.

Table 1. The Impact of a Vannamei Shrimp-Seaweed Polyculture System on Water Quality.

Type of Organism	**Environmental Factors**	**Results on Water Quality Parameters**	**Author**
Vaname Shrimp & Seaweed (*Gracilaria verrucosa*)	Temperature : 27-30 ^{0}C Salinity : 25-28 ppt	A seaweed density of 3.125 g/L is most effective at assimilating nitrogen from shrimp waste.	[11]
Vaname shrimp, *Gracilaria tenuistipitata*, and *Cladophora* sp.	Temperature : 26.8-30.3 ^{0}C pH : 7.8-8.2	Seaweed keeps TAN and orthophosphate levels low even when feed is reduced.	[10]
Vaname Shrimp, Milkfish, & Seaweed (*Gracilaria* sp.)	Temperature : 29.6–31.8 ^{0}C DO : 5.54-5.82 mg L^{-1} pH : 7.0-7.2 Salinity : 15.1-22 ppt	Primary productivity (temperature, salinity, nitrate, phosphate) is positively correlated with organism growth.	[26]
Black Tiger Shrimp (*P. monodon*) & Seaweed (*Gracilariopsis longissima*)	Temperature : 24.2 – 33.7 ^{0}C pH : 7.00 – 8.9 Salinity : 13.1 – 32.5	Seaweed acts as a natural biofilter that enhances the stability of the pond ecosystem.	[14]
Vaname Shrimp, Milkfish, & *Gracilaria verrucosa*	Temperature : 29.2 – 32.8 ^{0}C DO : 1.1 – 3.4 mg L^{-1} pH : 6.54 – 8 Turbidity : 24–50 cm	The addition of seaweed improves the environmental conditions for aquaculture in ponds.	[17]
Vaname Shrimp, Milkfish, & *Gracilaria verrucosa*	Temperature : 31.5–32.0 ^{0}C DO : 3.6-5.5 mg L^{-1} pH : 6.54–6.95 Turbidity : 40–45 cm	Low stocking density helps maintain carbon (C) balance in the pond ecosystem.	[18]
Tiger Prawns, Red Tilapia, & *Gracilaria verrucosa*	Temperature : 24.5-32.5 ^{0}C DO : 2.5-3.8 mg L^{-1} pH : 7.5-7.9	Red tilapia and seaweed effectively improve water quality in degraded ponds, keeping ammonia levels low.	[16]
Vaname Shrimp & *Gracilaria tenuistipitata*	Temperature : 26.3-31.7 ^{0}C pH : 7.22-8.00 Turbidity : 2.647 – 15.832 lux	Adding 2 kg/m^3 of seaweed maintains safe levels of TAN and nitrite up to a stocking density of 300 individuals/m^3	[25]
Vaname Shrimp & *Gracilaria* sp.	Temperature: 26.5 – 29.5 ^{0}C DO : 5.25 – 6.75 mg L^{-1} pH: 7.5 – 8.5 Turbidity: 21 cm	Seaweed planting density affects plankton abundance and dissolved oxygen (DO) levels in the pond.	[21]

Vaname Shrimp and *Caulerpa racemosa* Seaweed	Temperature: 25.3-29.5 ^{0}C DO : 4.75-6.87 mg L^{-1} pH: 7.5-8.5 Salinity: 23.5-30.5	Polyculture systems provide good synergy in improving water quality in flood-affected ponds.	[22]
Vaname Shrimp, Milkfish, *Gracilaria* sp., & *Eucheuma cottonii*	Temperature: 30-34.4 ^{0}C DO : 4.2-7.4 mg L^{-1} pH: 7.1-7.6 Turbidity: 60-80 cm	Water physicochemical parameters remain stable within a range suitable for the growth of shrimp and macroalgae.	[27]
Vaname Shrimp & Sea Grapes (*Caulerpa lentillifera*)	Temperature: 25.9 -27.6 ^{0}C DO : 4.72-5.28 mg L^{-1} pH: 8.10-8.29 Turbidity: 41-50 cm	Sea grapes effectively reduce TAN and orthophosphate levels significantly in intensive systems.	[2]
Vaname Shrimp (*L. vannamei*) & Red Seaweed (*Gracilaria corticata*)	Temperature: 30.4-35.8 ^{0}C DO : 5.1-6.36 mg L^{-1} pH: 7.3-8.7	Increased seaweed density significantly reduces the concentration of total ammonia nitrogen (TAN), nitrite, nitrate, and phosphate in the water and sediment.	[8]
Vaname Shrimp & Sea Grapes (*Caulerpa lentillifera*)	Temperature: 27.4–28.8 DO : 4.33–5.25 mg L^{-1} pH: 8.10–8.40 Turbidity: 43–50 cm	A seaweed density of 1 kg/m^3 provides the best water purification from shrimp metabolic waste.	[12]

3.4. The Impact of Shrimp and Seaweed Polyculture Systems on Productivity

The implementation of polyculture systems significantly improves shrimp growth performance by providing greater environmental stability compared to monoculture systems. The presence of seaweed as a natural biofilter component in polyculture systems has been shown to increase the Specific Growth Rate (SGR) and absolute weight of vanamei shrimp [18]. This is supported by findings that the integration of seaweed can increase overall shrimp biomass compared to cultivation without aquatic plants [11]. This faster growth occurs because seaweed helps maintain a stable supply of dissolved oxygen, which is crucial for shrimp metabolism and molting processes [17].

In addition to growth rates, polyculture systems have a very significant positive impact on shrimp survival rates (SR). The integration of *Gracilaria* sp. seaweed into aquaculture tanks increased the survival rate of vanamei shrimp from 63% to 83% [11]. Similar results were also found with the use of sea grapes (*Caulerpa lentillifera*), where the appropriate density of macroalgae resulted in a shrimp SR of 86.7% [12]. This high survival rate is attributed to the seaweed's ability to suppress toxic ammonia and nitrite concentrations in the water [25]. Seaweed contains bioactive compounds that significantly affect bacterial viability due to their content of alkaloids, saponins, flavonoids, steroids, and phenolics. Flavonoids are known to penetrate the cells of Gram-negative bacteria such as *Vibrio harveyi* and disrupt their metabolic processes [3] [20].

Feed conversion efficiency, or Feed Conversion Ratio (FCR), also showed significant improvement in polyculture systems. Shrimp reared alongside seaweed exhibited a more efficient FCR due to the availability of additional natural feed in the form of biofilm or detritus attached to the seaweed thallus [2]. In fact, reducing commercial feed rations by up to 25% in IMTA systems does not significantly reduce shrimp growth performance because the balanced ecosystem provides additional nutrients [10]. With lower FCR values, feed operational costs can be reduced, thereby increasing the economic productivity of the pond [25].

Overall, land productivity in polyculture systems is significantly higher than in monoculture systems due to crop diversification. This system allows farmers to generate income from shrimp, fish, and seaweed simultaneously within a single production cycle [16]. Therefore, polyculture can increase production quantities and ensure economic and ecological sustainability for coastal farming communities [5]. Factors such as seaweed density, light availability, and water quality significantly determine production outcomes. Under conditions where seaweed does not grow optimally, the benefits to the system are minimal or do not provide economic returns. Conversely, under optimal conditions, seaweed can improve system efficiency by enhancing water quality and serving as a potential additional feed source. The impact of the vanamei shrimp and seaweed polyculture system on water quality is shown in Table 2.

Table 2. The Impact of a Vannamei Shrimp-Seaweed Polyculture System on Productivity.

Type of Organism	Environmental Factors	Results on Productivity:	Author
Vaname Shrimp & Seaweed (*Gracilaria verrucosa*)	Temperature : 27-30 ^{0}C Salinity : 25-28 ppt	SR: Increased from 63% to 83%. Growth: Increased from 247.78 g to 350.20 g (biomass).	[11]
Vaname shrimp, *Gracilaria tenuistipitata*, and *Cladophora* sp.	Temperature : 26.8-30.3 ^{0}C pH : 7.8-8.2	Reducing feed by up to 25% did not significantly reduce shrimp performance. FCR was more efficient in the IMTA system.	[10]
Vaname Shrimp, Milkfish, & Seaweed (*Gracilaria* sp.)	Temperature : 29.6–31.8 ^{0}C DO : 5.54-5.82 mg L^{-1} pH : 7.0-7.2 Salinity : 15.1-22 ppt	Gracilaria harvest yields were higher in polyculture systems with milkfish compared to shrimp.	[26]
Black Tiger Shrimp (*P. monodon*) & Seaweed (*Gracilariopsis longissima*)	Temperature : 24.2 – 33.7 ^{0}C pH : 7.00 – 8.9 Salinity : 13.1 – 32.5	Shrimp production increased by 53.8% and seaweed by 18%	[14]
Vaname Shrimp, Milkfish, & *Gracilaria verrucosa*	Temperature : 29.2 – 32.8 ^{0}C DO : 1.1 – 3.4 mg L^{-1} pH : 6.54 – 8 Turbidity : 24–50 cm	The treatment with stocking density (Milkfish and Shrimp at 10 individuals/m^2, seaweed at 250 g/m^2) showed the most optimal daily growth rate for all three commodities.	[17]

Vaname Shrimp, Milkfish, & *Gracilaria verrucosa*	Temperature : 31.5–32.0 ^{0}C DO : 3.6-5.5 mg L^{-1} pH : 6.54–6.95 Turbidity : 40–45 cm	Best results in Treatment A (milkfish and shrimp 10 individuals/m², seaweed 250 g/m²): optimal SGR, absolute weight, and absolute length of shrimp, as well as optimal agar quality (yield).	[18]
Vaname Shrimp & *Gracilaria tenuistipitata*	Temperature : 26.3-31.7 ^{0}C pH : 7.22-8.00 Turbidity : 2.647 – 15.832 lux	SR reached 83.8–88.4%. FCR: More efficient at moderate shrimp stocking densities with the aid of a seaweed biofilter.	[25]
Vaname Shrimp & *Gracilaria* sp.	Temperature : 26.5 – 29.5 ^{0}C DO : 5.25 – 6.75 mg L^{-1} pH : 7.5 – 8.5 Turbidity : 21 cm	Highest SR (88%) at a seaweed planting distance of 45 cm. SGR: Faster daily weight gain in shrimp.	[21]
Vaname Shrimp and *Caulerpa racemosa* Seaweed	Temperature : 25.3-29.5 ^{0}C DO : 4.75-6.87 mg L^{-1} pH : 7.5-8.5 Salinity : 23.5-30.5	SR: 90% (Shrimp) & 90.25% (Seaweed). FCR: 1.65. Absolute Growth: 19.60 g (Shrimp) & 932 g (Seaweed).	[22]
Vaname Shrimp, Milkfish, *Gracilaria* sp., & *Eucheuma cottonii*	Temperature : 30-34.4 ^{0}C DO : 4.2-7.4 mg L^{-1} pH : 7.1-7.6 Turbidity : 60-80 cm	*E. cottonii* grew optimally with an initial weight of 3 kg, while *Glacilaria verrucosa* did not grow well, significantly improving land efficiency.	[27]
Vaname Shrimp & Sea Grapes (*Caulerpa lentillifera*)	Temperature : 25.9 - 27.6 ^{0}C DO : 4.72-5.28 mg L^{-1} pH : 8.10-8.29 Turbidity : 41-50 cm	Seaweed biomass increases; shrimp FCR improves; seaweed protein content increases.	[2]
Vaname Shrimp (*L. vannamei*) & Red Seaweed (*Gracilaria corticata*)	Temperature : 30.4-35.8 ^{0}C DO : 5.1-6.36 mg L^{-1} pH : 7.3-8.7	SR > 85–90%. A seaweed density of 400 g/m² resulted in shrimp harvests reaching an optimal point. Significant growth in seaweed biomass.	[8]
Vaname Shrimp & Sea Grapes (*Caulerpa lentillifera*)	Temperature : 27.4–28.8 DO : 4.33–5.25 mg L^{-1} pH : 8.10–8.40 Turbidity : 43–50 cm	Shrimp survival reached 86.7%. Growth: Shrimp weight increased faster than the control.	[12]

4. CONCLUSIONS

The polyculture system combining shrimp and seaweed is an aquaculture innovation that integrates production with environmental conservation through the principle of a balanced ecosystem. Research shows that seaweed acts as a natural bioremediation agent, absorbing excess nutrients from uneaten feed and shrimp waste, thus maintaining water quality and minimizing the risk of diseases caused by ammonia accumulation. In addition to improving environmental quality, this system integration also provides dual economic benefits for farmers through crop diversification and increased feed efficiency. Therefore, the implementation of polyculture can improve shrimp survival and growth while creating a farming model that is more resilient to the challenges of climate change and environmental degradation in coastal areas.

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