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VANAME SHRIMP CULTURE AT VARIOUS PRODUCTION SCALES: TECHNICAL AND ECONOMIC REVIEW (LITERATURE STUDY)

Budidaya Udang Vaname Pada Berbagai Skala Produksi: Tinjauan Teknis Dan Ekonomi (Studi Literatur)

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ABSTRAK

Budidaya udang vaname (*Litopenaeus vannamei*) berkembang dengan pesat di Indonesia dan memiliki berbagai skala produksi, mulai dari tradisional hingga super-intensif. Penelitian ini mengkaji perbedaan teknis serta ekonomi dari masing-masing skala produksi yang didasarkan pada studi pustaka. Pada skala intensif dan super-intensif, pemanfaatan teknologi seperti sistem bioflok, *Recirculating Aquaculture System* (RAS), dan *Internet of Things* (IoT) memungkinkan padat tebar yang lebih tinggi (80-150 ekor/m^2 dan 250-400 ekor/m^2) dengan produktivitas dapat mencapai 15-20 ton/ha/periode dan 100-150 ton/ha/periode. Secara ekonomi, skala produksi yang lebih intensif menunjukkan keuntungan yang lebih besar. Skala tradisional memiliki Internal *Rate of Return* (IRR) sebesar 10–20% dengan waktu pengembalian modal 3–5 tahun, sementara skala semi-intensif dan intensif memiliki IRR 20–50% dengan periode pengembalian modal lebih singkat (1,5–3 tahun). Skala super-intensif menawarkan keuntungan tertinggi dengan IRR >50%, Net Present Value (NPV) miliaran rupiah, dan periode pengembalian modal kurang dari 1,5 tahun. Namun, skala intensif dan super-intensif membutuhkan modal awal yang besar serta sistem manajemen yang lebih kompleks, terutama dalam aspek kualitas air dan biosikuriti. Hasil kajian ini menunjukkan bahwa peningkatan skala produksi dapat meningkatkan efisiensi dan keuntungan, tetapi juga membawa risiko yang lebih tinggi. Oleh karena itu, pemilihan skala produksi harus mempertimbangkan kesiapan teknis, sumber daya keuangan, serta manajemen risiko yang baik. Penerapan teknologi seperti bioflok, RAS, dan IoT berpotensi meningkatkan efisiensi serta keberlanjutan budidaya udang vaname. Dukungan dari pemerintah dan pemangku kepentingan sangat diperlukan untuk meningkatkan daya saing industri budidaya melalui kebijakan yang mendukung inovasi dan keberlanjutan.

Kata kunci: Udang vaname, skala produksi, aspek teknis, aspek ekonomi, teknologi akuakultur

ABSTRACT

Whiteleg shrimp (*Litopenaeus vannamei*) cultivation is growing rapidly in Indonesia and has various production scales, from traditional to super-intensive. This study examines the technical and economic differences of each production scale based on literature studies. On an intensive and super-intensive scale, the use of technologies such as the biofloc system, Recirculating Aquaculture System (RAS), and Internet of Things (IoT) allows for higher stocking densities (80-150 fish/m^2 and 250-400 fish/m^2) with productivity reaching 15-20 tons/ha/period and 100-150 tons/ha/period. Economically, a more intensive production scale shows greater benefits. The traditional scale has an Internal Rate of Return (IRR) of 10–20% with a payback period of 3–5 years, while the semi-intensive and intensive scales have an IRR of 20–50% with a shorter payback period (1.5–3 years). Super-intensive scale offers the highest profit with IRR> 50%, Net Present Value (NPV) of billions of rupiah, and payback period of less than 1.5 years. However, intensive and super-intensive scales require large initial capital and more complex management systems, especially in terms of water quality and biosecurity. The results of this study indicate that increasing the scale of production can increase efficiency and profits, but also carries higher risks. Therefore, the selection of production scale must consider technical readiness, financial resources, and good risk management. The application of technologies such as biofloc, RAS, and IoT has the potential to increase the efficiency and sustainability of whiteleg shrimp cultivation. Support from the government and stakeholders is needed to increase the competitiveness of the aquaculture industry through policies that support innovation and sustainability.

Keywords: Vaname shrimp, production scale, technical aspects, economic aspects, aquaculture technology.

INTRODUCTION

Whiteleg shrimp (*Litopenaeus vannamei*), one of the economically important aquaculture commodities in Indonesia and other shrimp producing countries in the world. This shrimp, which originates from tropical and subtropical waters on the coast of the Pacific Ocean, is especially found in the regions from Mexico to Peru. In its life cycle, whiteleg shrimp undergoes a series of development stages starting from eggs, nauplius, zoea, mysis, post-larvae, juveniles, to adults. In most cultivation practices, fry that have entered the post-larvae (PL) stage are usually released into ponds or closed systems that apply controlled environmental management, to increase the survival and growth of whiteleg shrimp (Pamungkas *et al.,* 2022).

Whiteleg shrimp has advantages compared to other shrimp species which make it a prime commodity in the aquaculture industry. Rapid growth, high feed efficiency, and the ability to adapt to variations in salinity make this shrimp very suitable for cultivation in brackish water ponds and seawater recirculation systems. According to Ramadani *et al.* (2024), whiteleg shrimp have been shown to have better resistance to various diseases when compared to tiger shrimp (*Penaeus monodon*). With proper management, whiteleg shrimp can reach harvest size within 75 to 120 days depending on stocking density, business scale, and feeding strategy applied (Arief *et al.,* 2015; Anton *et al.,* 2022; Wahyudi *et al.,* 2022).

To achieve optimal growth rates, whiteleg shrimp require suitable environmental conditions, such as water salinity between 15-25 ppt, water temperature ranging from 28-30°C, and fairly high dissolved oxygen levels (Wahyudi *et al.,* 2022). This ability to adapt to various environmental conditions allows for increased production and makes whiteleg shrimp a leading export commodity that makes a significant contribution to the national economy (Hidayat *et al.,* 2019). In line with increasing demand from both domestic and international markets, the whiteleg shrimp cultivation system continues to evolve with various scales and approaches to increase efficiency and productivity (Pamungkas *et al.,* 2022).

Whiteleg shrimp cultivation was introduced in Indonesia in the early 2000s as an alternative solution to the increasing cases of tiger shrimp production disruptions due to attacks by various types of diseases, such as White Spot Syndrome Virus (WSSV) and Early Mortality Syndrome (EMS). Since then, whiteleg shrimp cultivation has continued to grow rapidly, supported by continuously developing cultivation technology. The government through the Ministry of Maritime Affairs and Fisheries supports the development of vaname shrimp cultivation and various technologies, including intensive and super-intensive with the Recirculating Aquaculture System (RAS), and the Internet of Thing (IoT) for real-time water quality monitoring (Nugraha *et al.,* 2023).

Indonesia has become one of the largest whiteleg shrimp producing countries in the world, exporting its main products to several countries, such as the United States, Japan, China, and the European Union (Pratama, 2023). Whiteleg shrimp cultivation in various production scales, ranging from traditional with simple technology to super-intensive based on modern technology, has even developed. Each production scale has its own characteristics in terms of technical and economic aspects (Sianturi & Maniko, 2023). Traditional scales tend to use natural methods with little human intervention, while super-intensive scales apply advanced technology to increase stocking density, feed efficiency, and water quality management (Wahyudi *et al.,* 2022). Biofloc, RAS, and IoT-based water quality monitoring are technologies that have been widely used in modern systems for better production efficiency and environmental sustainability (Renitasari & Musa, 2020).

However, intensive cultivation systems have many challenges. High production costs, the need for trained labor, disease risks, and complex water quality management are some of the challenges faced by shrimp farmers (Ritonga *et al.,* 2021). Diseases such as *Vibrio* spp. and WSSV virus infections are still major threats to vaname shrimp farming activities. Thus, a strict biosecurity system and water quality management are the keys to success in a more advanced farming system (Pamungkas *et al.,* 2022).

Based on the diversity of approaches in production scale and the various challenges that exist, a comprehensive study is needed to understand the technical and economic differences of each cultivation system. This study is important so that farmers can choose the system that best suits the conditions of the resources and capacities they have (Zakaria *et al.,* 2021). Thus, the applied vaname shrimp cultivation strategy can be more efficient, sustainable, and provide optimal economic benefits. This study aims to analyze various scales of vaname shrimp cultivation production based on their technical and economic aspects through a literature study approach. It is hoped that the results of this study can provide useful information for farmers, academics, and stakeholders in formulating a vaname shrimp cultivation development strategy that is more adaptive to the challenges and opportunities of the aquaculture industry in the future.

RESEARCH METHODS

This study uses a literature study method by collecting and analyzing data from various previous studies related to whiteleg shrimp cultivation on a traditional, traditional-plus, semi-intensive, intensive, and super-intensive scale. This method includes secondary data collection, comparative analysis, economic feasibility evaluation, and identification of challenges and recommendations. Secondary data was obtained from scientific journals, research reports, and publications related to whiteleg shrimp cultivation on various production scales. The data obtained were compared based on the main parameters such as stocking density, survival rate (SR), Feed Conversion Ratio (FCR), and productivity per hectare/cycle. Assessment of the economic aspect was carried out by analyzing the comparison of the Internal Rate of Return (IRR), Payback Period, and Net Present Value (NPV) of whiteleg shrimp cultivation on various production scales. With this approach, this study is expected to provide a more comprehensive picture of the technical and economic factors in whiteleg shrimp cultivation as well as solutions that can be applied to increase the productivity of whiteleg shrimp cultivation sustainably.

RESULT

Technical Aspects of Vaname Shrimp Cultivation at Various Production Scales

Based on the production scale, vanname shrimp cultivation in Indonesia can be categorized into 5 (five), namely traditional, traditional-plus, semi-intensive, intensive, and super-intensive. These various levels of production scale are distinguished not only based on stocking density, but also feed management programs, water quality management, pest and disease control, use of technology such as waterwheels/aerators, automatic feeding devices (autofeeders), and IoT, as well as application of treatments such as the use of probiotics, and so on (Table 1).

Table 1. Stages of Vaname Shrimp Cultivation Based on Production Scale

Cultivation Stages	**Production Scale**				
	Traditional	**Traditional-Plus**	**Semi-Intensive**	**Intensive**	**Super-Intensive**
Pond Preparation	Natural pond bottom cleaning without drying	Pond drying and simple fertilization	Total drying, fertilization and improvement of soil quality	Use of HDPE, strict sterilization and biosecurity	Use of HDPE with strict recirculation and biosecurity systems
Maintenance Water Preparation	Relying on natural water without filtration	Simple water filtration and use of lime for sterilization	Filtration, sedimentation, sterilization of water with chlorine or probiotics	Full aeration system, filtration, sterilization and regular monitoring	Biofloc/recirculation system with IoT based monitoring
Spreading of Benur	Direct spread without strict acclimatization	Simple acclimatization before spreading the fry	Acclimatization with temperature control, salinity, and probiotic administration	Controlled acclimatization with probiotics and vaccination	IoT-based acclimatization, high-quality seed selection
Feeding	Natural food from plankton	Providing additional feed in the form of bran and pellets	Commercial feed with manual feeding schedule and additional probiotics.	Automatic feeding with real-time monitoring	IoT based automated feeding and controlled nutrition
Water Quality Management	No regular water changes	Manual water changes in limited quantities	Controlled water changes, simple aeration, and water quality monitoring	Strict biosecurity, real-time water quality monitoring	Biofloc/recirculation system with automatic waste management and IoT monitoring
Pest and Disease Control	Relying on the natural balance of the pond ecosystem	Use of lime and natural fermentation to prevent disease	Use of probiotics, regular sanitation, and simple waste management	Vaccination program, probiotics, and close monitoring	High-level biosecurity, vaccination and disease detection based on IoT
Harvest and Post-Harvest	Manual harvest without size selection	Manual harvesting with size selection based on market demand	Scheduled harvests, simple grading, and use of harvesting aids	Harvesting with technology-based size and quality grading	Automated harvesting with IoT-based grading

References: various sources

Based on Table 1, the stages of vaname shrimp cultivation production greatly influence the increase in the complexity of technical aspects based on the scale of production. This is very reasonable, because along with the increase in production scale, the technology and innovation used are also increasingly advanced. The traditional scale still relies on environmental factors, does not use aeration, and utilizes natural feed. The traditional-plus scale shows that there have been improvements, such as pond management, feed, and water quality. The semi-intensive scale has started to use aeration technology and water quality management, and the intensive scale utilizes complete technology such as the use of aeration, water quality management, and biosecurity. Meanwhile, the super-intensive scale relies heavily on high technology, such as water recirculation, autofeeders, and water quality sensors equipped with IoT systems.

The increase in the complexity of technical aspects based on the scale of production shows significant variations in the number of stocking densities, feed efficiency (FCR), survival rate (SR), productivity, and DOC (Table 2).

Table 2. Stocking Density, FCR, SR, Productivity, and DOC of Vaname Shrimp Cultivation Based on Production Scale

Production Scale	Stocking Density (head/m²)	FCR	SR (%)	Productivity (ton/ha/period)	DOC (Day)
Traditional	5-9	NA	30-50	0.1-0.5	$\leq$120
Traditional-Plus [a)]	10-49	1.8-2.0	50-70	0.7-1.5	$\leq$120
Semi-Intensive [b)]	50-79	1.5-1.8	$\geq$70	4-8	75-120
Intensive [c)]	80-150	1.2-1.5	$\geq$75	15-20	90-120
Super-Intensive [d)]	250-400	1.0-1.3	>85	100-150	$\leq$120

Reference: [a)] SNI 8117:2015; [b)] SNI 8007:2014, SNI 7772:2013; [c)] SNI 7246-2006; [d)] SNI 8118:2015

Based on Table 2, the traditional scale is the simplest vaname shrimp cultivation system with a low stocking density of around 5–9 fish/m², SR 30-50%, with a productivity of 0.1–0.5 tons/ha/period. The traditional-plus scale shows an increase in stocking density of around 10–49 fish/m², FCR begins to improve to 1.8–2.0, SR increases to 50–70%, and productivity reaches 0.7–1.5 tons/ha/period. Meanwhile, the stocking density on a semi-intensive scale is around 50-79 fish/m², FCR becomes more efficient around 1.5-1.8, SR increases to above 70%, and productivity is much higher between 4-8 tons/ha/period. Furthermore, on an intensive scale, the stocking density increases to 80–150 fish/m², the FCR is even more efficient at around 1.2–1.5, the SR is high at around 75%, and productivity can reach 15–20 tons/ha/period. While the super-intensive scale is at the highest level with a stocking density of 250–400 fish/m², very high feed efficiency with an FCR of 1.0–1.3, SR above 85%, and productivity can exceed 100–150 tons/ha/period.

Economic Aspects of Vaname Shrimp Cultivation at Various Production Scales

Economic aspects are one of the main factors in determining the scale of vaname shrimp cultivation production. The analysis of economic aspects aims to compare the economic feasibility of various scales of vaname shrimp cultivation production based on the Internal Rate of Return (IRR), Payback Period, and Net Present Value (NPV). IRR is used to determine the level of return on investment in the long term, Payback Period to determine the time needed to return the initial investment, while NPV to determine the net profit value after taking into account the time value of money.

Table 3. Economic Analysis of Various Scales of Vaname Shrimp Cultivation Production

Production Scale	**Indicator**		
	IRR (%)	**Payback Period (Year)**	**NPV (Rp Million)**
Traditional	10-15	4-5	50-150
Traditional-Plus	15-20	3-4	150-300
Semi-Intensive	20-30	2-3	400-700
Intensive	30-50	1.5-2	1,000-2,000
Super-Intensive	>50	<1.5	>3,000

References: various sources (processed)

Based on Table 3, it shows that traditional scale whiteleg shrimp cultivation has a low IRR of around 10-15%, indicating a longer return on investment. The payback period tends to be long, around 4-5 years, indicating that the investment takes longer to return. With some management improvements, the traditional-plus scale has a higher IRR of around 15-20%, and profits increase with an NPV of 150-300 million rupiah, while the payback period is shorter than the traditional scale. The Semi-Intensive Scale has a better IRR of around 20-30% with a shorter payback period of around 2-3 years and a higher NPV, indicating better profitability than the traditional method. The Intensive Scale has a greater profit with an IRR of 30-50% and a payback period of 1.5-2 years, the NPV reaches 1-2 billion rupiah, indicating very good investment feasibility, but higher production costs require more efficient management. Super-Intensive scale offers the highest return on investment with IRR of more than 50%, NPV of more than 3 billion rupiah, and payback period below 1.5 years, but higher initial investment and risk. From the results of this analysis, it can be seen that the higher the scale of production, the higher the economic efficiency, but intensive and super-intensive scales require large initial investment and more sophisticated water and feed management technology to optimize productivity and profits.

DISCUSSION

Technical Aspects of Vaname Shrimp Cultivation at Various Production Scales

Traditional Scale

Traditional-scale vaname shrimp cultivation is the simplest method and is still widely used by farmers with limited capital and technology. Ponds in the traditional system are generally land ponds with an average area of 1 ha/plot, shallow depth, and rely on the ebb and flow (Nurdin *et al.,* 2022). Pond bottom cleaning is carried out naturally by relying on drying and sedimentation of mud sedimentation without additional processing. No water sterilization or additional fertilization is carried out, so that pond fertility is highly dependent on the balance of the natural ecosystem without the application of aeration or filtration technology (Hidayat *et al.,* 2019). The water used comes from natural sources such as rivers or high tides that enter the pond without additional filtration or sterilization processes. Water quality is not strictly controlled, so fluctuations in water parameters often occur, resulting in high mortality due to disease attacks and suboptimal water quality (Dewi *et al.,* 2022).

The shrimp fry are released into the pond without going through a controlled acclimatization process, causing the shrimp SR to be lower than other scales. Stocking densities are generally low, ranging from 5–10 fish/m² to reduce shrimp competition in utilizing the availability of natural feed (Mira *et al.,* 2022; Pamungkas *et al.,* 2022; Dewi *et al.,* 2020), where shrimp rely on natural feed, such as plankton and detritus (Nurdin *et al.,* 2022; Dewi *et al.,* 2020). The use of organic fertilizers or fermentation of organic materials is often used to increase the productivity of natural feed in ponds. Artificial/additional feed is not provided routinely, so shrimp growth tends to be slower and more varied compared to more advanced systems.

During the maintenance process, there is no routine water change, because ponds generally do not have reservoirs. Water changes are carried out naturally through the ebb and flow mechanism that allows water to enter and exit the pond (Arief et al., 2015). There is no aeration treatment or oxygen level management, so water quality is highly dependent on environmental factors (Pratama, 2023). This scale has weaknesses in terms of disease resistance, due to the high accumulation of organic matter which can increase ammonia and nitrite levels in ponds. Disease control relies on the natural balance of the ecosystem, without the use of probiotics, vaccinations, or strict biosecurity (Ansarullah & Nurwarsito, 2022). To prevent pest and disease attacks, farmers usually change the water at high tide, liming, and administer organic pesticides, such as saponin, ketapang leaves and so on.

Harvesting is done manually without size selection, so that the harvest has quite a large variation in size. Shrimp are sold directly after harvest without going through a grading process or further handling such as implementing a cold chain. This can reduce the quality of shrimp which can affect the selling price in the market to be low. In addition, productivity in this system is relatively low, around 0.1-0.5 tons/ha/period. Research by Nurdin et al. (2022) in Indramayu, West Java, showed that the productivity of traditional-scale vaname shrimp cultivation ranged from 0.1-0.3 tons/ha/period. Meanwhile, research by Putri et al. (2020) in East Lampung, showed that the productivity of traditional-scale vaname shrimp cultivation was around 0.5 tons/ha/period.

Traditional-plus Scale

Along with the increasing understanding of shrimp farmers regarding cultivation efficiency, the traditional-plus scale has developed, which is a development of the traditional scale with several improvements in technical aspects, such as pond management, feed, and water quality. Although still dependent on natural factors, this system has begun to adopt several simple technologies to increase productivity.

In the traditional-plus system, the pond bottom soil is dried and turned over before the cultivation cycle begins to reduce the potential for pathogens in the pond bottom mud (Arief *et al.,* 2015). In addition, treatments using agricultural lime and organic fertilizers are carried out to increase the fertility of the pond bottom soil through plankton growth (Wahyudi *et al.,* 2022; Ramadani *et al.,* 2024; Sianturi & Maniko, 2023). The water used comes from natural sources but simple filtration begins before entering the pond. The shrimp fry used in this system undergo simple acclimatization before being released into the pond. The acclimatization process includes gradual adjustment of temperature and salinity to increase shrimp SR (Pamungkas *et al.,* 2022). In addition to relying on natural feed, in the traditional-plus system, additional feed in the form of bran, commercial pellets, and probiotics are given to support shrimp growth (Renitasari & Musa, 2020; Hidayat *et al.,* 2019). Artificial feed is given if the availability of natural feed is reduced. The frequency of feeding is 1-3 times/day with a dose of 2-5% of shrimp biomass (SNI 8117:2015).

Water replacement is done manually in limited amounts to maintain the balance of the pond ecosystem. Simple aeration has begun to be applied to increase dissolved oxygen levels (Pratama, 2023; Wahyudi et al., 2022). The use of agricultural lime and fermentation of organic materials such as molasses has begun to be applied as a natural method in preventing disease. In addition, waste management is carried out better than on a traditional scale (Ansarullah & Nurwarsito, 2022; Cahyono *et al.,* 2023).

Vannamei shrimp are maintained on a traditional-plus scale until they reach DOC 120 days or the shrimp size has reached a minimum of 7 grams/tail. Harvesting is done manually but has begun to implement a size selection/sorting system before being sold to the market to increase the selling value of the shrimp (Anton *et al.,* 2022; Zakaria *et al.,* 2021). The advantages of the traditional-plus scale compared to the pure traditional scale are an increase in SR of up to 50-70%, as well as an increase in productivity to 0.7-1.5 tons/ha/period. With the application of simple aeration and more controlled feeding, feed efficiency also increased with FCR ranging from 1.8 to 2.2. However, this system still faces challenges in managing organic waste and the risk of disease due to water quality that is not fully controlled. Although this system has limitations, traditional and traditional-plus scale cultivation is still an option for farmers who have limited capital and access to more sophisticated technology. However, to improve sustainability and productivity, a transition to a semi-intensive scale with better water quality management is highly recommended.

Semi Intensive Scale

In semi-intensive vaname shrimp production scale, ponds are dried first before use. Drying aims to remove pathogens and excessive organic matter. In addition, ponds are also given dolomite lime and fertilizer to increase the fertility of the pond bottom soil (Wahyudi *et al.,* 2022). The water used goes through a filtration and sedimentation process before being channeled to the maintenance plot. Water quality is controlled by using probiotics or certain chemicals to stabilize pH and reduce the potential for disease (Supono *et al.,* 2021).

On a semi-intensive scale, the stocking density of vaname shrimp is around 50-79 tails/m2. Before being stocked, the fry go through an acclimatization stage, namely adjusting the temperature and salinity of the pond water. This aims to increase the SR of the fry (Pamungkas *et al.,* 2022). Shrimp are given commercial feed with more controlled calculations. Feed management is more controlled compared to the traditional scale, using artificial feed that is given on a schedule. Feed is given with a frequency of 2-6 times/day and a dose of 75-2% biomass/day adjusted based on the maintenance age (Day of Culture/DOC) and shrimp biomass (SNI 7772:2013; SNI 8007:2014). Thus, the frequency of feeding is directly proportional to DOC, while the feed dose is inversely proportional where the feed dose decreases as the DOC increases. The use of probiotics in feed and maintenance media is also applied to increase feed efficiency and maintain shrimp health (Ramadani *et al.,* 2024). Feed efficiency on this scale is better, with FCR ranging from 1.5-1.8 (Nugraha *et al.,* 2023).

Water quality management is carried out with a periodic water replacement system and monitoring of key parameters such as pH, dissolved oxygen (DO), temperature, and salinity. Aeration uses a water wheel to increase dissolved oxygen in the pond (Mahendra, 2023). In intensive shrimp farming, aeration is an important component to maintain dissolved oxygen (DO) levels above 4 ppm, with the use of 2-4 aerator units/ha to support better water circulation (Purnamasari *et al.,* 2020). In addition, the use of water reservoirs is applied to maintain the stability of the pond environment, although still on a limited scale. Semi-intensive scales still have limitations in filtration systems and waste management, the accumulation of organic matter at the bottom of the pond is still a challenge that must be overcome.

The use of probiotics and natural ingredients such as plant extracts is often applied to control diseases. Probiotics containing *Lactobacillus plantarum, Lactobacillus casei* and *Lactobacillus fermentum* aim to control water quality and increase shrimp immunity (Abidin, 2022). Pond sanitation is carried out periodically to prevent infection from pathogens that can cause diseases such as WSSV and vibriosis (Ansarullah & Nurwarsito, 2022). The maintenance period for vaname shrimp on this scale is around 75-120 days or reaches a consumption size of around 11 (90 tails/kg) to 22 grams/tail (45 tails/kg). Harvesting is done selectively by sorting based on shrimp size. A more uniform harvest usually has a higher selling price than a harvest without size selection. The use of harvesting aids has also begun to be implemented to reduce stress on shrimp and increase work efficiency (Zakaria *et al.,* 2021).

Some of the advantages of semi-intensive scale are higher productivity compared to traditional scale, better survival with more controlled aeration and feeding, and lower investment compared to intensive and super-intensive scale. The main challenge in this system is the management of water quality which is not yet fully optimal, especially in terms of controlling ammonia and nitrite levels which still have the potential to increase due to the accumulation of organic matter (Pratama, 2023). Therefore, several farmers who use semi-intensive scale have begun to apply additional technology such as the use of probiotics and simple biofiltration to improve the stability of the pond environment (Rasyidah *et al.,* 2024).

Intensive Scale

In intensive scale vaname shrimp farming systems, ponds use High-Density Polyethylene (HDPE) layers to reduce the risk of leakage and accumulation of organic waste on the pond bottom (Mulyani *et al.*, 2024). The pond sterilization process is carried out with dolomite lime and disinfectants to ensure the environment is free from pathogens before the water is filled into the pond (Ritonga *et al.,* 2021; Cahyono *et al.,* 2023). The water used in intensive cultivation goes through a multi-stage filtration process to remove solid particles and pathogens. Sterilization using chlorine or ultraviolet light is often applied to ensure optimal water quality before entering the pond (Wahyudi *et al.,* 2022; Pratama, 2023).

The distribution of fry is carried out with strict acclimatization, including adjusting the temperature, salinity, and pH of the water. The fry used come from certified hatcheries with high biosecurity standards to prevent the entry of diseases (Mulyani *et al.,* 2024; Pamungkas *et al.,* 2022; Ansarullah & Nurwarsito, 2022). On an intensive scale, the stocking density of vaname shrimp is around 80-150/m^2. Before being stocked, the fry go through an acclimatization stage, namely adjusting the temperature and salinity of the pond water. Feed is provided automatically using autofeeder or IoT technology to ensure even feed distribution. Feeding is adjusted to the growth rate and environmental conditions. Feed is provided with a frequency of 3-5 times/day and a dose of 75-2% biomass/day adjusted based on DOC and shrimp biomass (SNI 7246:2006).

Intensive feed management is carried out using an index feeding approach, namely a feeding system that is adjusted to the shrimp's appetite (Renitasari *et al.,* 2021). This system is supported by regular monitoring of the anco and the use of IoT sensors to detect feed consumption in real time to prevent underfeeding or overfeeding (Anton *et al.,* 2022; Pratama *et al.,* 2023). Underfeeding can inhibit shrimp growth, non-uniform and porous size, and high cannibalism activity, while overfeeding can reduce water quality which can cause shrimp stress, decreased shrimp resistance to disease, and even high mortality (Renitasari *et al.,* 2021). With good feed management, FCR can be reduced to 1.2-1.5, better than the semi-intensive scale which has an FCR of 1.5-1.8 (Prawitasari & Rafiqie, 2022; Ramadani *et al.,* 2024; Lailiyah *et al.,* 2018).

Water quality management on an intensive scale is very strict, including measuring parameters such as dissolved oxygen (DO), pH, temperature, and ammonia levels using IoT sensors. According to Mahendra *et al.* (2023), the application of a water wheel can maintain oxygen needs and increase the production of whiteleg shrimp in intensive ponds. The application of the water wheel aims to support the diffusion of oxygen into the pond water so that the DO value remains at an optimal level for the functioning of the ecosystem and shrimp life (Purnamasari *et al.,* 2019). The use of water reservoirs is also standard in this system to reduce fluctuations in pond environmental parameters (Mulyani *et al.,* 2024).

Water quality in intensive shrimp farming is controlled through the application of RAS which allows efficient use of water (Rasyida et al., 2024; Nugraha et al., 2023). This system uses a combination of mechanical filtration, biofiltration, and UV sterilization to reduce levels of ammonia, nitrite, and organic matter that can cause stress to shrimp. The application of the Closed Recirculation System (CRS) and biofloc in the management of organic waste from intensive ponds can affect water quality (Pamungkas et al., 2022). In addition, biosecurity is strictly implemented through the use of probiotics, vaccination, and high-quality water filtration to prevent diseases such as white spot syndrome virus (WSSV) and vibriosis. Shrimp health monitoring is carried out routinely by examining samples in the laboratory (Anton et al., 2022; Sianturi & Maniko, 2023).

Harvesting is carried out in stages or partially with size grading to reduce density and accelerate shrimp growth (Aras & Faruq, 2024). Partial harvesting should be done slowly to avoid stress on the shrimp. The use of automatic harvesting aids can also be used to help reduce stress on the shrimp and maintain the quality of the harvest. The first partial harvest is generally carried out at a maintenance age of around 2 months, while the second partial harvest is around 0.1-1 months or adjusted to the density and growth rate of the shrimp. Total harvesting is generally carried out at a maintenance age of 90-120 days or the size of the shrimp has reached 20 grams/head or a size of 50 heads/kg (Wahyudi *et al.,* 2022). After harvesting, a waste management system is implemented to maintain the balance of the pond environment and reduce the impact of pollution. The intensive scale offers much higher productivity compared to the semi-intensive scale, reaching 15-20 tons/ha/period. With SR> 75%, this system provides greater economic benefits compared to conventional systems. Research by Anton *et al.* (2022) in Donggala, Central Sulawesi, reported that the SR of vaname shrimp on an intensive scale was 90% with an FCR of 1.72, while research by Pamungkas *et al.* (2022), reported that the average SR reached 84.67% with an FCR of 1.5.

The main advantages of this scale include high productivity with a more optimal management system, efficient water use through the RAS system, reduced disease risk through the implementation of CRS, biofloc, and better biosecurity, and greater economic benefits with more efficient feed and aeration management. However, the challenge in intensive scale is the high initial investment cost, especially for the installation of aeration, filtration systems, and IoT devices. In addition, this system requires more skilled workers to operate the technology used. Therefore, for farmers who want to implement an intensive scale, careful planning is needed in managing capital and human resources.

Super-Intensive Scale

Super-intensive vaname shrimp farming generally uses High-Density Polyethylene (HDPE) lined ponds or round ponds with a RAS system. Pond sterilization is carried out using dolomite lime, disinfectants, and ultraviolet light to prevent contamination of pathogenic microbes (Renitasari & Musa, 2020; Pamungkas *et al.,* 2022). The water used must go through strict filtration, ozone or ultraviolet light sterilization, and sedimentation before being introduced into the pond system. Water quality is monitored in real-time using IoT-based sensors to ensure optimal parameters (Zakaria *et al.,* 2021; Pratama, 2023). According to Pratama (2023), the super-intensive scale fully adopts the RAS system, allowing efficient repeated use of water. Water in the pond is processed through several stages of filtration, including mechanical filtration, biofiltration, denitrification, and UV sterilization, to remove excess organic matter and prevent disease contamination.

The fry used in this system come from certified hatcheries with strict selection based on size and disease resistance with a stocking density of > 300/m^2 (Mulyani *et al.,* 2024; Renitasari & Musa, 2020; Lailiyah *et al.,* 2018; Pamungkas *et al.,* 2022). The acclimatization process involves adjusting the temperature, pH, and salinity of the water before stocking to ensure high SR (Lailiyah *et al.,* 2018; Ansarullah & Nurwarsito, 2022). Feeding uses high-quality feed with optimal protein formulation for rapid growth and lower FCR (Ramadani *et al.,* 2024; Wahyudi *et al.,* 2022) with automation technology based on Artificial Intelligence (AI) and IoT, allowing the system to accurately detect feed requirements based on shrimp consumption levels. Feed is given with a frequency of 4-24 times/day and a dose of 25-2% biomass/day adjusted based on DOC and shrimp biomass (SNI 8118:2015). The use of automatic feed throwing machines is carried out starting from DOC 31-45 days with a frequency of 12 times/day, while for DOC more than 45 days as much as 24 times/day.

The use of the index feeding method can be combined with underwater camera monitoring to adjust the amount of feed given (Purnamasari *et al.,* 2020). Providing index feeding system can increase feed efficiency and the growth of vaname shrimp (Renitasari *et al.,* 2021). With the application of this technology, FCR can be reduced to 1.0-1.3, much more efficient than the intensive scale which has an FCR of 1.2-1.5 (Prawitasari & Rafiqie, 2022; Renitasari *et al.,* 2021).

The high stocking density on this scale can result in the accumulation of organic matter which can cause disease and cultivation failure (Abidin *et al.,* 2022). Water quality management in super-intensive systems is very strict, using a biofloc or RAS system. Biofloc helps control ammonia levels, while sophisticated aeration systems use blowers and oxygen diffusers to maintain optimal dissolved oxygen (DO) levels (Sianturi & Maniko, 2023; Cahyono *et al.,* 2023). The use of aeration in this system is also more sophisticated than intensive scale, with a combination of blowers, water wheels, oxygen diffusers, and pure oxygenation systems to ensure dissolved oxygen (DO) levels remain above 5-6 ppm (Rasyidah *et al.,* 2024).

Water quality monitoring is carried out in real-time using IoT, allowing early detection of water parameter fluctuations and rapid corrective action (Pratama *et al.,* 2023). Biosecurity in super-intensive systems is implemented very strictly. The use of probiotics, vaccination, and laboratory-based shrimp health monitoring are carried out routinely to prevent diseases such as Early Mortality Syndrome (EMS) and White Spot Syndrome Virus (WSSV) (Anton *et al*., 2022; Ritonga *et al.,* 2021). Harvesting is carried out automatically with mechanical devices to reduce stress on the shrimp. A sensor-based grading system is used to sort shrimp by size before being packed and sent to the market. Harvest waste is managed with a wastewater treatment system to maintain environmental sustainability (Pamungkas *et al.,* 2022).

Super-intensive whiteleg shrimp farming offers the highest productivity compared to other scales, reaching 100-150 tons/ha/period. With higher SR and optimal feed efficiency, this scale provides greater economic benefits (Renitasari & Musa, 2020; Lailiyah *et al.,* 2018). The success of maintaining vaname shrimp with a super-intensive production scale is carried out by implementing 5 cultivation sub-systems, namely the use of quality seeds, health and environmental management, the application of appropriate cultivation technology, the use of standard cultivation facilities and infrastructure and implementing modern business management (Ramadani *et al.,* 2024).

The main advantages of this scale include very high productivity with maximum stocking density, optimal water efficiency through the RAS system, the use of IoT and AI technology for feed management and water quality monitoring, and better biosecurity, with strict control over potential disease infections. With very strict water quality management and the application of an IoT-based feeding system, this system can achieve the highest productivity compared to other scales (Renitasari & Musa, 2020; Lailiyah *et al.,* 2018; Pamungkas *et al.,* 2022). This scale has several challenges, including very high investment costs for the construction of aeration, filtration, and IoT infrastructure systems, which require highly skilled workers to manage the technology used (Pratama, 2023).

Economic Aspects of Vaname Shrimp Cultivation at Various Production Scales

Return (IRR), Net Present Value (NPV), and Payback Period (PP) are economic indicators that show that whiteleg shrimp farming is generally a financially feasible business activity, both on a small, medium, and large scale. Based on the research results, whiteleg shrimp farming has been proven to be generally financially feasible. However, the amount of feasibility varies depending on the scale of cultivation production used, the efficiency of production inputs, and the management strategy applied. This is reflected in the main economic indicators such as IRR, NPV, and PP which consistently show positive results at various scales of cultivation production. However, the value of these indicators is greatly influenced by the scale of production applied, the efficiency of production inputs, and the management strategy used.

In intensive and super-intensive systems, the potential for profit is very large. Research by Maulana *et al.* (2022) in Aceh Tamiang recorded an IRR of 163%, NPV reaching IDR 19 billion, and PP for 0.6 years. Research by Ariadi *et al.* (2019), Wafi *et al.* (2021), and Putra & Intyas (2022) in Probolinggo, East Java, recorded IRR reaching 27.55%, 37.23%, and 109% respectively, NPV of IDR 19 billion, IDR 34 billion, and IDR 36 billion respectively, while PP was for 5 years, 2.7 years, and 1 year respectively. Meanwhile, research by Aprilia *et al.* (2020) in Barru, South Sulawesi reported IRR reaching 25.4%, NPV of IDR 3.77 billion, and PP for 1.95 years.

Similar results were found in research by Ariadi *et al.* (2021) in Banten, recording IRR of 33.10%, NPV of IDR 77 billion and PP for 3.6 years. Meanwhile, research by Purwanto *et al.* (2024) in Tegal showed an average IRR of 2.35%, NPV of IDR 1 billion, and PP for 1.9 years. These findings confirm that investment in intensive and super intensive cultivation systems is very economically attractive, especially when supported by optimal feed management and water quality.

The semi-intensive scale also showed good performance. Hilal *et al.* (2019), research in Sumenep, East Java, recorded an IRR of 56.65%, NPV of IDR 680.8 million, and PP for 3.94 years. Meanwhile, Khatimah's (2022) research in Parangtritis, Special Region of Yogyakarta, reported an IRR of 17.27%, NPV of IDR 135 million, and PP for 1.9 years. This confirms that the semi-intensive system is a strategic choice with a balanced investment and risk ratio.

In traditional and traditional-plus scale cultivation such as in Pangkal Pinang, Bangka Belitung Islands, and Sambas, West Kalimantan, economic indicators such as PP of less than 1 year still indicate business feasibility, although the NPV and IRR values are relatively lower than the semi-intensive scale. Rahmadina et al.'s research. (2022) in Pangkal Pinang, recorded an R/C ratio of 2.38 and PP for 0.47 years. Meanwhile, research by Arisa *et al.* (2024) in Sambas, West Kalimantan, showed an R/C ratio of 2.63 and PP for 3.25 years. Although the profit is smaller, the advantage of this production scale is the low risk and capital requirements, making it suitable for development for novice farmers or those with limited access to capital.

In general, it shows that the higher the intensification of the scale of cultivation production, the greater the potential profit that can be obtained. The intensive system provides the highest economic results, but with high risks and capital. The semi-intensive system offers a good balance between investment, risk, and results. Meanwhile, the traditional system remains relevant for small farmers who prioritize sustainability and capital accessibility. The use of innovative technologies such as microbubble systems, plastic tarpaulin ponds, and digital-based management has also been proven to increase business efficiency and accelerate capital returns. Thus, the economic indicators IRR, NPV, and PP consistently show that the vaname shrimp cultivation business is an activity that is not only feasible, but also financially promising if managed with the right approach.

CONCLUSION

Vaneneme shrimp cultivation at various production scales shows significant differences in technical and economic aspects. Technically, the higher the production scale, the greater the need for technological intervention, ranging from the use of aeration, water quality management, feed management, biosecurity, to the use of advanced technologies such as RAS, biofloc, and the Internet of Things (IoT). This has a direct impact on optimizing stocking density, feed efficiency (FCR), productivity, and shrimp survival rate (SR). Traditional scale with a stocking density of 5-9 fish/m^2 has a productivity of 0.1-0.5 tons/ha/period and SR 30-50%, while traditional-plus scale with a stocking density of 10-49 fish/m^2 with additional feed and fertilization of pond bottom soil has better productivity of around 0.7-1.5 tons/ha/period and SR 50-70%. Semi-intensive scale adopts simple aeration technology and water quality control with a stocking density of 50-79 fish/m^2, can produce productivity of 4-8 tons/ha/period and SR above 70%. Intensive scale applies full aeration and real-time monitoring system with a stocking density of 80-150 fish/m^2, productivity can reach 15-20 tons/ha/period and SR above 75%. While super-intensive scale by utilizing RAS technology, biofloc, IoT to support a stocking density of 250-400 fish/m^2, productivity can reach 100-150 tons/ha/period and SR more than 85%.

Economically, whiteleg shrimp farming has generally proven to be financially feasible, as indicated by key economic indicators such as Internal Rate of Return (IRR), Net Present Value (NPV), and Payback Period (PP). The values of these indicators consistently show positive results at various production scales, from traditional to super-intensive. However, the level of financial feasibility is greatly influenced by the scale of production, input efficiency, and management strategies applied. Businesses with intensive and super-intensive cultivation systems show the highest profit potential with IRRs that can reach more than 100% and relatively short payback periods, but require careful management and large capital. Semi-intensive systems offer a good balance between investment and risk, with economic results that remain profitable. Meanwhile, traditional systems remain relevant for farmers with limited resources, due to low investment requirements and lower risks. Therefore, vaname shrimp cultivation is a financially promising business activity if managed with an efficient and sustainable approach.

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