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Strategy for Developing Whiteleg Shrimp (*Litopenaeus vannamei*) Culture Using Intensive/Super-Intensive Technology in Indonesia

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Abstract: The Government of the Indonesian Republic has targeted an increase in the value of shrimp exports and production until 250% by 2024. Thus, a special strategy is needed to develop whiteleg shrimp (*Litopenaeus vannamei*) culture that can increase production but does not negatively impact the aquatic environment. For this reason, research was carried out to obtain a strategy for developing sustainable intensive/super-intensive technology of whiteleg shrimp culture in South Sulawesi Province, Indonesia. The activity was conducted in South Sulawesi Province from March to July 2021. The data were collected from questionnaires submitted to respondents or actors, namely whiteleg shrimp brackishwater pond managers and other stakeholders and structured observations on whiteleg shrimp ponds. The validity of the questionnaire was tested using Corrected Item-Total Correlation method and the reliability was tested using Cronbach's alpha method. Another primary data source was obtained through Focus Group Discussion. Data analysis was undertaken using the Analytical Hierarchy Process method. The research results show that, of the 18 intensive/super-intensive technology of whiteleg shrimp farming businesses operating in Bulukumba, Je'neponto, and Takalar Regencies, only one whitleg shrimp farming business applies super-intensive technology. The main problems in intensive/super-intensive whiteleg shrimp culture are disease attacks, namely acute hepatopancreatic necrosis disease or early mortality syndrome and white feces disease and the inconsistent quality of seed. Among the four criteria studied, it was found that environmental factor criteria are the most influential in developing intensive/super-intensive technology of whiteleg shrimp culture. Among the seven alternative strategies, the order of priority of the alternative strategies is environmental protection of culture, management of culture areas, modern technological innovation, environmentally friendly culture technology, easy access to business and capital, improvement of human resources, and availability of pond facilities.

Keywords: brackishwater pond; development strategy; Indonesia; intensive/super-intensive technology; whiteleg shrimp

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1. Introduction

Tiger shrimp (*Penaeus monodon*) and whiteleg shrimp (*Litopenaeus vannamei*) are aquaculture commodities in Indonesia. The Ministry of Marine Affairs and Fisheries of the Republic of Indonesia has targeted an increase in export value and shrimp production of 250% by 2024. Therefore, this needs to promote Indonesian brackishwater pond's intensification and extensification [1,2].

South Sulawesi Province is one of the shrimp culture centers in Indonesia. In 2015, tiger shrimp and whiteleg shrimp production was ranked second and eighth in Indonesia [3]. The area of ponds reached 108,465 ha in 2019 [4]. The ponds used for culture with traditional (extensive), semi-intensive, and intensive technologies of 102,277, 5490, and 698 ha, respectively. Although the data do not indicate the existence of a super-intensive technology for whiteleg shrimp culture, additional information has been implemented [5–7]. According to Athirah [7], there is potential for the extensification of super-intensive whiteleg shrimp culture in several regencies in South Sulawesi Province, such as Pinrang, Barru, and Bulukumba. Consequently, the development can still be carried out by intensification and extensification. Intensification can occur on intensive technology where land conditions allow for super-intensive technology. At the same time, extensification can be carried out on new land where conditions allow for super-intensive technology. Considering the possibility of many conflicts due to extensification, the development of whiteleg shrimp culture is more focused on intensification.

The super-intensive technology has a 1000 m^2 pond area; hence, it is easy to control, the water depth is more significant than 1.8 m, it has high stocking density (>500 ind./m^2), increased productivity, minimal waste load, and is equipped with clean water reservoirs and a wastewater treatment plant (WWTP) [6]. This technology's development can potentially increase environmental pollution due to increased feed use [8,9]. In aquaculture systems, inadequate nutrient inputs inhibit shrimp growth, while excessive inputs lead to environmental degradation and unnecessarily high investment [10,11]. Waste load on whiteleg shrimp culture with a stocking density of 500 ind./m^2 in 1000 m^2 ponds is 50.12 g of total N/kg of shrimp, 15.73 g total P/kg shrimp, and 126.85 g C organic/kg shrimp. Waste that is difficult to decompose by microorganisms causes hoarding and damage to the environment, directly interfering with organisms living in the environment [9,12,13]. In intensive technology whiteleg shrimp culture with a stocking density of 110–220 ind./m^2 and productivity between 13.9–44.4 tons/ha/cycle, the waste load is predicted to reach 28.00 tons N/cycle and 6.61 tons P/cycle [14].

Intensive/super-intensive technology whiteleg shrimp ponds in the south of South Sulawesi Province (Takalar, Je'neponto, and Bulukumba Regencies) take and dispose of water in the Flores Sea. In the Flores Sea, the Taka Bonerate National Park was designated a United Nations Educational, Scientific and Cultural Organization (UNESCO) Biosphere Reserve in 2015 [15,16]. Taka Bonerate National Park, which is located in the Selayar Islands Regency, South Sulawesi Province, has an area of 530,765 ha and an atoll area of 220,000 ha, which is the largest atoll or coral reef in Indonesia and Southeast Asia, and the third largest in the world after Kwajalein Atoll (Marshall Islands) and Suvadiva Atoll (Maldive Islands) [17]. In areas where there are very dense activities around the atoll, negative impacts can be received by pollution, nutrient enrichment, changes in construction in the field (dredging for boat access, filling for housing construction, sand mining, and others), and exploitation of enormous resources [18–20].

Previous research in Kaur Regency, Bengkulu Province, discovered various problems in intensive technology development: disease attacks and decreased environmental carrying capacity in whiteleg shrimp culture [21]. Meanwhile, Barru Regency, South Sulawesi Province, detected disease attacks, climate change, pollution, and land conversion [22]. Intensification of shrimp ponds is suspected of causing negative and positive impacts, leading to various environmental and socio-economic problems [23]. Based on the characteristics of intensive and super-intensive whiteleg shrimp culture, which demands specific requirements, and the possible impact of the waste, a certain strategy is also needed to ensure productivity remains high and sustainable in Kaur Regency. Nardiyanto et al. [21] stipulated that the strategies for developing the aquaculture business are (a) planning production management to meet demand on time, quantity, and quality; (b) carrying out production management planning by implementing good aquaculture practices (GAqP); (c) increasing the volume of production by utilizing and optimizing the land owned; (d) cooperating with the government to obtain solutions to various obstacles faced; and (e) collaborating with academics to conduct research and business development. However, the problems and alternative strategies for developing intensive/super-intensive whiteleg shrimp culture may differ. Therefore, this research goal is to obtain a strategy for developing a sustainable intensive/super-intensive technology in aquaculture in the South Sulawesi Province, Indonesia. To achieve this goal, the research question has been focused on alternative strategies to be considered in determining the development of intensive/super-intensive technology whiteleg shrimp culture. Based on the above, this research aims to investigate the hypothesis that the alternative strategies obtained may be used as alternative solutions in the context of decision making regarding the development of intensive/super-intensive technology whiteleg shrimp culture. This research is significant because it focuses analytically on decision making based on the right method used in actual conditions in one of the whiteleg shrimp production centers in Indonesia, namely South Sulawesi Province, to ensure success in intensive/super-intensive technology whiteleg shrimp culture in other regions in Indonesia.

2. Materials and Methods

2.1. Research Location and Time

The research was carried out in intensive/super-intensive technology whiteleg shrimp brackishwater ponds in Bulukumba, Je'neponto, and Takalar Regencies, South Sulawesi Province (Figure 1), and at various central, provincial, and local government levels in Makassar City, South Sulawesi Province. Furthermore, it was conducted in institutions related to pond culture in Makassar City and related agencies at the local government level in Bulukumba, Je'neponto, and Takalar Regencies, from March to July 2021.

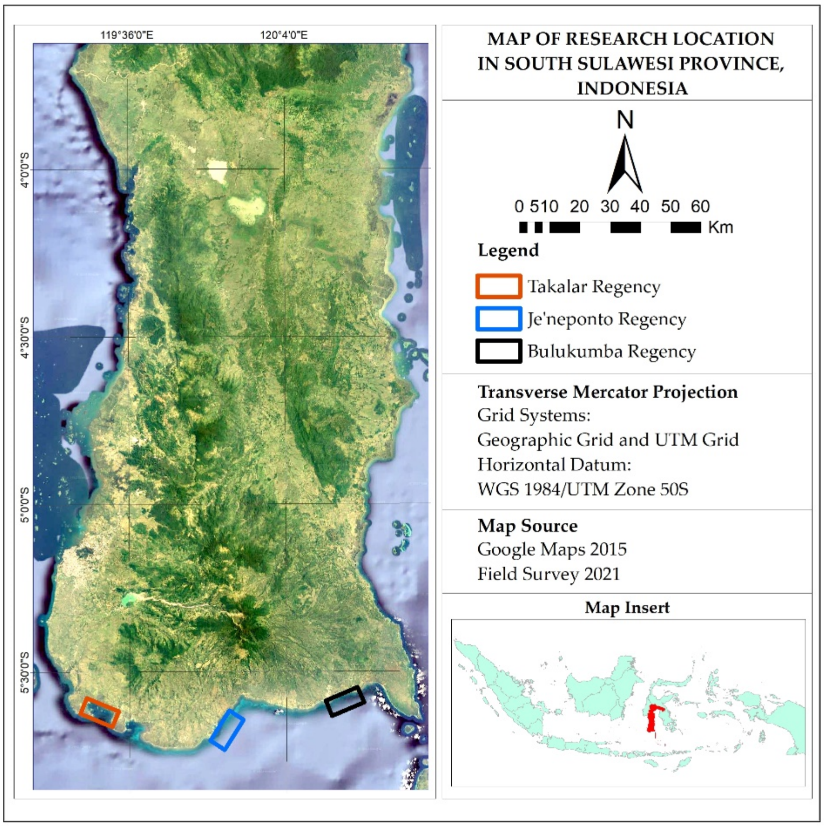

Figure 1. Research location for developing intensive/super-intensive technology in whiteleg shrimp farming ponds in Bulukumba, Je'neponto, and Takalar Regencies, South Sulawesi Province, Indonesia (courtesy of La Ode Muhamad Hafizt Akbar, Ministry of Marine Affairs and Fisheries).

2.2. Data Collection

Data collection started with compiling a list of Analytical Hierarchy Process (AHP) questionnaires and conducting an inventory of respondents or actors with internal discussions. The questionnaire is one of the most widely used instruments to collect data, especially in social science research [24,25]. Data collection is in the form of primary and secondary data. Primary data were obtained from the questionnaires submitted to respondents or actors as managers of intensive/super-intensive whiteleg shrimp ponds in Bulukumba, Je'neponto, and Takalar Regencies, relevant agencies at the central, provincial, and local government levels, universities that have fisheries study programs, research institutes, and other associated institutions through in-depth interviews and structured observations. Additional primary data from whiteleg shrimp pond profiles were obtained from record keeping by farmers and direct observations in ponds. Meanwhile, the selected respondents were determined through a purposive sampling method. There were 52 respondents consisting of 5 respondents from the central government level, 2 respondents from the provincial government level, 20 respondents from the local government level, 18 respondents from shrimp farming, 3 respondents from the research institute and fisheries extension, 2 respondents from university, and 2 respondents from the Indonesian shrimp farmers association.

Another primary data source was Focus Group Discussion (FGD), and the leading resource is the Expert Staff of the Coordinating Ministry for Maritime Affairs and Investment of the Republic of Indonesia, the Head of the Marine and Fisheries Service of South Sulawesi Province, and Secretary of Shrimp Club Indonesia (SCI) South Sulawesi. Secondary data from the pond area were obtained from the Marine and Fisheries Service of South Sulawesi Province from 2014 to 2020 [4,26–30].

2.3. Data Analysis

The main objective of the questionnaire in research is to obtain the most valid and reliable relevant information. Before analyzing the internal consistency validity and reliability, a descriptive analysis was conducted, including the normality assessment of the variables. The validity and reliability test can be established using a pilot test by collecting data from 30 respondents according to Bolarinwa's [24] instructions. The validity and reliability tests of the questionnaire were conducted using Corrected Item-Total Correlation and Cronbach's alpha methods, respectively [31–33], using Statistical Package for the Social Sciences (SPSS) software. Corrected Item-Total Correlation is the most commonly used measure of validity and Cronbach's alpha is the most commonly used measure of internal consistency reliability [34,35].

Analysis using the AHP method is illustrated by a hierarchy, as shown in Figure 2. Decision-making is accomplished through the arrangement, which, according to Saaty [36], is described in the system's structure. The hierarchical function between components and their impact on the entire system can be studied to determine the priority of decision-making in determining the strategy for intensive/super-intensive technology in whiteleg shrimp culture. It is composed of three levels, each consisting of various elements that will assist the selection of alternatives. From the highest to the lowest, the main targets to be achieved are developing intensive/super-intensive technology, influencing factors, and alternative strategies.

After summarizing the questionnaire, data processing was carried out using the AHP method to determine the developing intensive/super-intensive whiteleg shrimp culture with the help of Microsoft Office Excel. The AHP method supports decision-making on several alternative options [37–39]. AHP provides a rational framework for a needed decision by quantifying its criteria and alternative options, relating those elements to the overall goal, and evaluating alternative solutions [40].

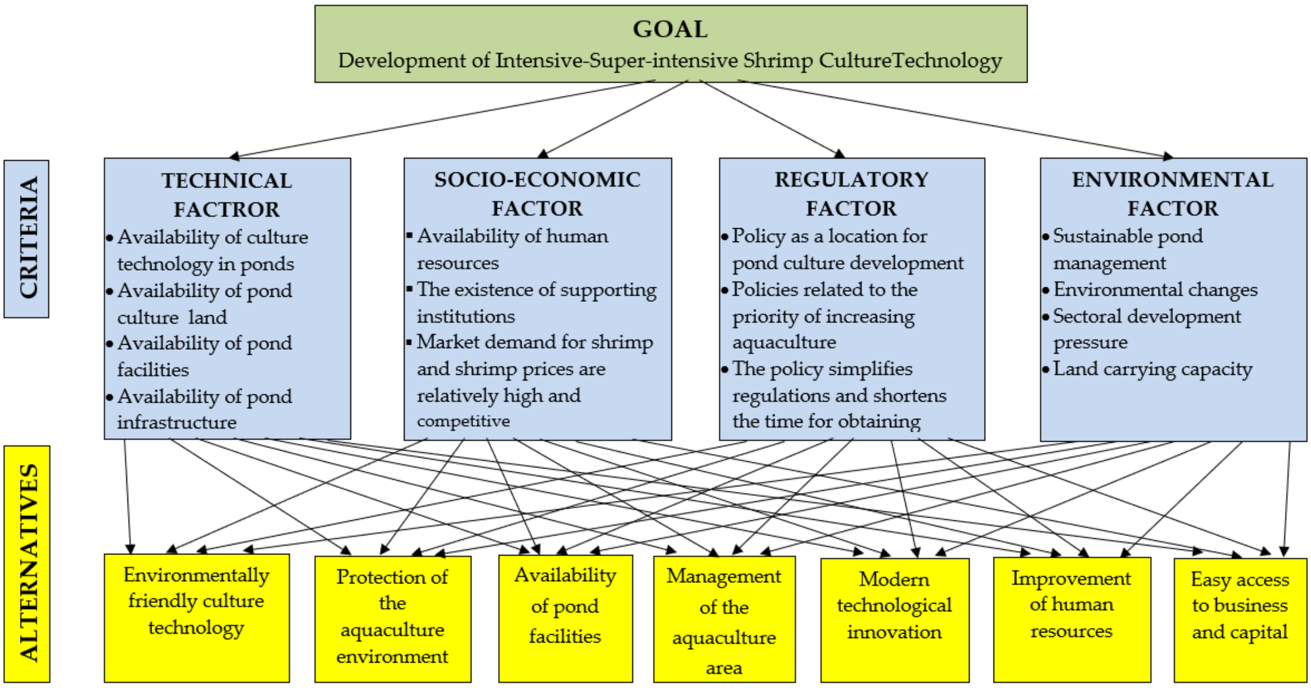

Figure 2. The Analytical Hierarchy Process method for determining strategies for developing intensive/super-intensive technology in whiteleg shrimp culture in Bulukumba, Je'neponto, and Takalar Regencies, South Sulawesi Province, Indonesia.

3. Results and Discussion

3.1. Pond Culture Profile

Brackishwater ponds in South Sulawesi Province are found on the west, south, and east coast. The pond area reached 109,561.00 ha in 2014 [26] and 108,465.30 ha in 2019 [4]. The ponds are spread over 19 of 24 regencies/cities [41], and the areas in Bulukumba, Je'neponto, and Takalar Regencies were 3876, 2460, and 3979 ha, respectively, in 2019 (Figure 3).

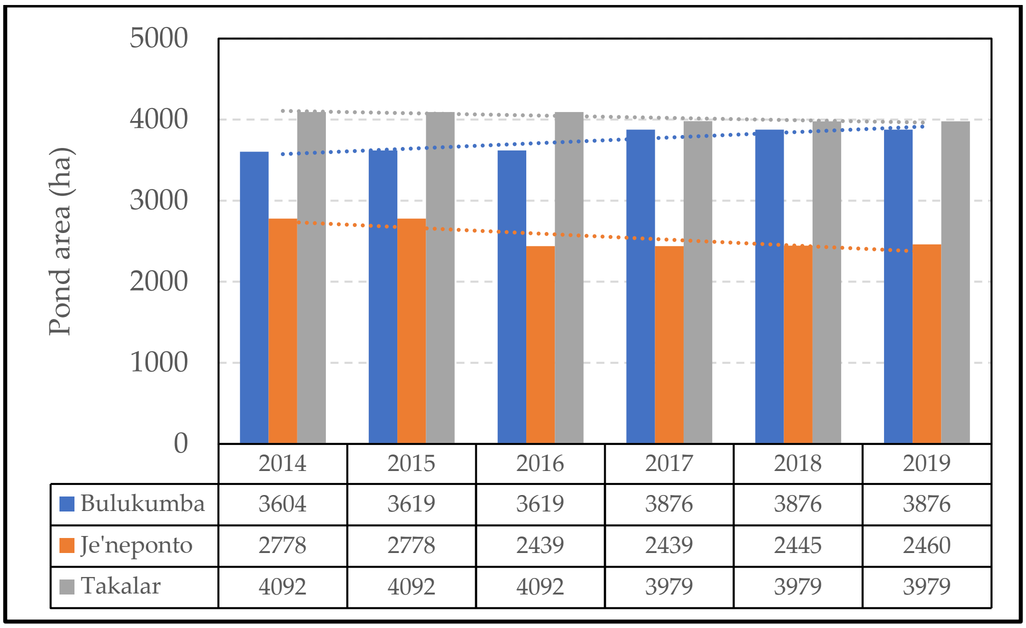

Figure 3. Pond area in Bulukumba, Je'neponto, and Takalar Regencies, South Sulawesi Province, Indonesia from 2014 to 2019 [4,26–30].

Ponds in South Sulawesi Province are used to culture brackishwater commodities. It uses extensive and intensive technology aquaculture with an area of 102,277.47 ha and 697.77 ha representing 94.30% and 0.64% of the total pond area, respectively. For ponds with intensive/super-intensive technology, 469.80 ha or 67.33% are included in the research location. Therefore, it can represent the condition of intensive/super-intensive ponds in South Sulawesi Province.

Regarding the intensive/super-intensive ponds in Bulukumba, Je'neponto, and Takalar Regencies, there are 8, 6, and 6 whiteleg shrimp farming businesses, respectively. Of the 20 businesses, 18 were included as research objects, while 2 were excluded because they were not operating when the research was being conducted. However, only 1 of the 18 operating businesses applied the super-intensive technology. It was a pond located in the Mangarabombang Sub-district, Takalar Regency. Furthermore, intensive/super-intensive ponds were found in Bontobahari, Ujung Bulu, and Gantarang sub-districts (Bulukumba Regency); Bangkala, Binamu, and Arungkeke sub-districts (Je'neponto Regency); and Galesong, South Galesong, and Mangarabombang sub-districts (Takalar Regency).

Referring to the three research locations, intensive shrimp ponds in Takalar Regency were constructed in 1997 and began operation in 1998 (Table 1). Ponds in Je'neponto Regency were the last to apply intensive technology in 2018 and operated in the same year.

Table 1. Pond profile and performance of intensive/super-intensive whiteleg shrimp culture in Bulukumba, Je'neponto, and Takalar Regencies, South Sulawesi Province, Indonesia.

Variables	Regencies		
	Bulukumba (*n* = 7)	**Je'neponto (*n* = 6)**	**Takalar (*n* = 5)**
Year of constructed	2009–2017	2006–2019	1997–2018
Year of operational	2010–2021	2016–2019	1998–2019
Total land area (ha)	0.3–45.0	0.8–15.0	0.5–30.0
Reservoir pond area (ha)	0.01–4.32	0.04–0.80	0.04–4.00
Wastewater treatment plant pond area (ha)	0.01–1.50	0.01–0.12	0.004–3.00
Pond area (m^2)	1600–5000	600–4900	720–6000
Number of the pond (units)	1–48	2–32	2–53
Total pond area (ha)	0.20–17.28	0.24–8.50	0.31–18.54
Stocking density (ind./m^2)	100–220	150–270	120–1.250
Partial harvest age (days)	60–95	60–97	60–75
Shrimp size at first partial harvest (ind./kg)	60–80	60–80	80–110
Age of total harvest (days)	100–120	90–120	95–120
Shrimp size at total harvest (ind./kg)	26–59	30–60	25–70
Feed conversion ratio	1.2:1–1.7:1	1.3:1–1.7:1	1.2:1–1.5:1

The total land area of intensive/super-intensive ponds for each whiteleg shrimp farming business varied from 0.3 ha to 45.0 ha. However, a small amount of the land was in the form of ponds, administrative buildings, laboratory buildings, biosecurity buildings, feed warehouses, shrimp medicine warehouses, aquaculture equipment warehouses, workshops, generator/State Electricity Company (*Perusahaan Listrik Negara* (*PLN*)—Indonesia's national power company) buildings, pond guard houses, harvest buildings, clean water reservoir ponds, WWTP ponds, and roads. Whiteleg shrimp culture ponds, clean water reservoir ponds, and WWTP ponds were constructed using concrete or high-density polyethylene (HDPE).

The area of clean water reservoir ponds varied from 0.01 to 4.32 ha in Takalar and Bulukumba Regency, depending on the pond being irrigated. The reservoir ponds had a capacity of at least 30% of the volume of rearing water individually and collectively [36]. In addition, the WWTP pond area varied considerably from 0.004 to 3.0 ha, depending on the total pond area where the water will be managed before being discharged into the sea. According to the level of shrimp culture technology, the intensive and super-intensive technologies have a volume of WWTP ponds of at least 20% and 30% of the total rearing media with a residence time of at least 2 and 5 days [42]. Depending on the technology applied, the pond area varied from 600 to 6000 m^2 (Table 1). In super-intensive technology, the pond area was relatively small, namely 1000 m^2. However, some small ponds of 600–720 m^2 did not apply the super-intensive technology because this was only the remaining land used for whiteleg shrimp culture. The pond area was also commonly determined by land conditions. Intensive technology was applied with relatively large sizes of 2400 and 6000 m^2. Tantu et al. [43] used 1000 and 1600 m^2 ponds with super-intensive technology in Barru Regency. According to Hopkins et al. [44], Islam et al. [45], and Islam [46], shrimp rearing and productivity are easier and higher in smaller ponds than in larger ones. In relatively small ponds, shrimp farming practices are relatively safe because fewer shrimp are affected when disease attacks. The risk of whiteleg shrimp farming can be reduced in smaller ponds.

To reduce shrimp biomass in ponds, the manager performed the first partial harvest, which is accomplished between 60 and 97 days. The number of partial harvest frequencies highly depends on biomass conditions and water quality, especially dissolved oxygen during culture, but the highest frequency is four times/cycle. There is no definite target for the partial harvest. Even in intensive technology culture with 100 ind./m^2 density in Bulukumba Regency, they did not conduct partial harvests. The size of the first partial harvest ranged from 60 to 110 ind./kg and could increase total production by increasing individual growth and survival rate by reducing competitive pressure [47–49].

The total harvest was carried out when the shrimp were 90 to 120 days old with various sizes of 26 to 70 ind./kg. Primarily, pond production is determined by stocking density, pond area, and technical problems affecting growth and survival rate. The highest productivity was found at a stocking density of 1250 ind./m^2 in an area of 1000 m^2, which produced 12.6 tons/1000 m^2. The high productivity is a significant opportunity to increase whiteleg shrimp production in Indonesia.

Even though productivity is relatively high, various problems are encountered in the whiteleg shrimp culture. The difficulties in whiteleg shrimp culture with intensive/super-intensive technology include disease attacks, low seed quality, environmental quality degradation, unfavorable climatic conditions at certain times, low culture management, low quantity and quality of human resources, and high feed and fluctuating shrimp prices. Disease attack is the biggest problem experienced by almost all the whiteleg shrimp businesses examined. The disease attacked at the research location is acute hepatopancreatic necrosis disease (AHPND), known as early mortality syndrome (EMS), which started attacking in 2018. In 2017, an outbreak was experienced in which the symptoms and physical characteristics were similar to AHPND/EMS in Aceh Besar Regency (Aceh Province), Mamuju Regency (West Sulawesi Province), and Barru Regency (South Sulawesi Province) (Circular Letter Number 799/BKIPM/X/2017 about Control of Acute Hepatopancreatic Necrosis Disease (AHPND)/Early Mortality Syndrome (EMS). Another disease identified is white feces disease (WFD). Meanwhile, WFD has also been reported to attack shrimp in intensive farming in Rembang Regency, Central Java Province [50]. These two diseases are produced by the bacterium vibrio, as demonstrated by the bacterium *Vibrio parahaemolyticus* and by the premature death of shrimp, even 30 days after the stocking of seed. The disease development of AHNDP/EMS was caused by vibrio bacteria that produce toxins of *pirA* and *pirB* as these genetic characteristics can be obtained by other vibrio bacteria apart from *V. parahaemolyticus* [51,52]. Another related complaint is the slow growth of whiteleg shrimp, non-uniform size, and susceptibility to disease and environmental changes, leading to low production. The low quality of seed can come from the quality of the broodstock, which is indeed low and reared in a hatchery with poor facilities and infrastructure, as well as poor work standards such as low biosecurity implementation and ignoring standard operating procedure (SOP).

3.2. Development Strategy

By using valid and reliable research instruments in data collection, the measurement results are expected to be valid and reliable. Therefore, a valid and reliable research instrument is an absolute requirement to obtain accurate data. Validity explains how well the collected data cover the actual subject of investigation [53,54]. Validity basically means "measure what is intended to be measured" [55,56]. The validity test results obtained a Corrected Item-Total Correlation value of 0.355–0.805 (Table 2). The Corrected Item-Total Correlation was above the recommended level of 0.3, indicating that all items correlated well with a total score and were acceptable [57,58]. According to Cristobal et al. [59], the items with a Corrected Item-Total Correlation higher than 0.30 are acceptable.

Table 2. The validity test result of the questionnaire in determining the strategy for developing intensive/super-intensive whiteleg shrimp culture in Bulukumba, Je'neponto, and Takalar Regencies, South Sulawesi Province, Indonesia.

	Scale Mean If Item Deleted	Scale Variance If Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha If Item Deleted
Comparison of objective criteria (A)				
A1	18.0333	114.447	0.761	0.768
A2	17.4667	107.844	0.805	0.756
A3	18.4000	116.041	0.671	0.787
A4	18.7333	142.271	0.402	0.837
A5	17.9667	136.447	0.376	0.846
A6	18.0667	120.409	0.605	0.802
Comparison of alternative technical criteria (B)				
B1	26.8333	199.385	0.391	0.866
B2	25.4667	185.016	0.608	0.833
B3	25.7333	184.340	0.736	0.818
B4	26.3333	187.126	0.537	0.845
B5	25.6667	183.195	0.652	0.827
B6	26.7000	177.597	0.713	0.818
B7	25.8667	177.913	0.716	0.818
Comparison of alternative socio-economic criteria (C)				
C1	24.2333	167.082	0.355	0.808
C2	23.4667	165.292	0.428	0.795
C3	23.4333	146.599	0.628	0.759
C4	23.3000	154.424	0.506	0.783
C5	22.5667	140.668	0.730	0.740
C6	23.7333	160.271	0.482	0.786
C7	22.6667	144.782	0.624	0.760
Comparison of alternative regulatory criteria (D)				
D1	23.8000	169.959	0.363	0.864
D2	22.0667	148.961	0.636	0.826
D3	22.9333	147.444	0.654	0.824
D4	23.9667	161.413	0.510	0.844
D5	22.2000	147.131	0.658	0.823
D6	23.4667	148.671	0.694	0.818
D7	21.9667	142.516	0.772	0.806
Comparison of alternative environmental criteria (E)				
E1	26.3000	150.286	0.451	0.756
E2	25.1000	150.300	0.387	0.771
E3	25.1667	144.489	0.480	0.751
E4	25.4333	143.771	0.519	0.743
E5	23.7333	135.375	0.652	0.715
E6	25.9333	144.616	0.543	0.738
E7	23.7333	151.030	0.463	0.754

Reliability concerns the extent to which a measurement of a phenomenon provides stable and consistent results [60,61]. Reliability is also concerned with repeatability. For example, a scale or test is reliable if its repeated measurement under constant conditions gives the same result. Testing for reliability is important as it refers to the consistency across the parts of a measuring instrument [62,63]. For internal consistency reliability, it was found that the Cronbach's alpha was 0.775–0.853 (Table 3). Based on the interpretation of the internal consistency reliability value, it can be confirmed that the internal consistency reliability of the research instrument or questionnaire is good. Straub et al. [64] and Saidi and Siew [65] stated that the research instrument is highly reliable if the Cronbach's alpha value is 0.70–0.90. No absolute rules exist for the Cronbach's alpha value, but most agree on a minimum Cronbach's alpha value of 0.70 [66,67]. In conclusion, the questionnaire has good validity and reliability and can be used effectively to investigate the alternative strategy for developing a sustainable intensive/super-intensive technology in aquaculture in the South Sulawesi Province, Indonesia.

Table 3. The reliability test result of the questionnaire in determining the strategy for developing intensive/super-intensive whiteleg shrimp culture in Bulukumba, Je'neponto, and Takalar Regencies, South Sulawesi Province, Indonesia.

Criteria	Cronbach's Alpha	Number of Items
Comparison of objective criteria	0.830	6
Comparison of alternative technical criteria	0.853	7
Comparison of alternative socio-economic criteria	0.803	7
Comparison of alternative regulatory criteria	0.851	7
Comparison of alternative environmental criteria	0.775	7

The criteria set in the development of intensive/super-intensive whiteleg shrimp culture are (a) technical, (b) socio-economic, (c) regulatory, and (d) environmental factors (Figure 2). Alternative options are environmental protection for culture, availability of pond facilities, management of culture areas, modern technological innovation, improvement of human resources, and ease of access to business and capital (Figure 2).

The analysis obtained a weight value for each criterion, as presented in Table 4. The criterion with the highest weight value is the environmental factor at 0.311 or 31.1% of the overall weight. This shows that the environment is the most critical factor to be considered because it is closely related to the life and growth of whiteleg shrimp. Subsequently, this factor becomes a determining criterion at the research location. Based on further AHP calculations, the Consistency Ratio (CR) value obtained is 0.008. Therefore, this weighting result can be accepted and is said to be consistent because it meets the requirements of the AHP principle, namely CR < 0.1 (<10%). As stated by Padmowati [37], Prakoso et al. [50], Zhu et al. [67], and Yang et al. [68], when CR < 0.1, the degree of consistency is satisfactory, meaning that the AHP method produces an optimal solution.

Table 4. Hierarchical weighting factor matrix for all normalized criteria determining the strategy for developing intensive/super-intensive whiteleg shrimp culture in Bulukumba, Je'neponto, and Takalar Regencies, South Sulawesi Province, Indonesia.

Criteria Comparison Matrix	Technical	Socio-Economic	Regulatory	Environment	Weight
Technical	0.279	0.334	0.292	0.240	0.286
Socio-economic	0.177	0.213	0.215	0.251	0.214
Regulatory	0.181	0.188	0.190	0.197	0.189
Environment	0.363	0.265	0.303	0.313	0.311

Based on the global priority matrix, each alternative receives a total weight, as shown in Table 5. The priority for developing intensive technology culture at the research location follows the priority order: protection of the environment, management of aquaculture areas, modern technological innovation, environmentally friendly culture technology, easy access to business and capital, improvement of human resources, and availability of pond facilities (Table 5).

Table 5. The total weight of each alternative and ranking in determining the strategy for developing intensive/super-intensive whiteleg shrimp culture in Bulukumba, Je'neponto, and Takalar Regencies, South Sulawesi Province, Indonesia.

Alternatives	Total Weight	Ranking
Protection of the aquaculture environment	0.162 or 16.2%	1
Availability of pond facilities	0.106 or 10.6%	7
Management of the aquaculture area	0.158 or 15.8%	2
Modern technological innovation	0.156 or 15.6%	3
Improvement of human resources	0.126 or 12.6%	6
Environmentally friendly culture technology	0.155 or 15.5%	4
Easy access to business and capital	0.137 or 13.7%	5

As previously mentioned, the main problem with intensive/super-intensive whiteleg shrimp culture is disease attacks. This is in line with the AHP method: the environmental factor has the most significant weight among the four evaluated criteria, namely technical, socio-economic, regulatory, and environmental (Table 4). Effective management measures are urgently needed to reduce adverse environmental impacts [20,23,69]. In this case, ecological quality improvement is expected to prevent disease attacks. Further results from the AHP method also found that an alternative that became the primary strategy is protecting the aquaculture environment. This alternative is closely related to the efforts to reduce the threat of disease attacks. It has been mentioned previously that AHPND/EMS is the primary disease that attacks the intensive/super-intensive whiteleg shrimp culture, also known as transboundary disease. This disease first appeared in China (circa 2009), referred to as covert mortality disease and has since been detected in Viet Nam in 2011, Malaysia in 2011, Thailand in 2012, Mexico in 2013, and the Philippines in 2015. Furthermore, it was allegedly discovered in several other countries in Asia, Latin America, and the Caribbean [70] and finally seen in Indonesia in 2017 (Circular Letter Number 799/BKIPM/X/2017).

Suggested action plans include controlling and improving the aquaculture environment (Table 6), such as determining land suitability and carrying capacity, monitoring water quality, and managing waste. Development must be based on an area supported by land suitability and carrying capacity. Therefore, land damage does not occur by decreasing environmental functions and financial losses as an economic function. Simultaneously implementing these two functions will bring double short-term and long-term benefits, namely economic and sustainable environmental functions. In this case, it is possible to control the aquaculture environment by determining the land suitability and carrying capacity. This is because the level of technology and the area of the pond that can be cultured follow the ability of the land, which does not cause a negative impact on the aquaculture environment. The carrying capacity can be considered integral to aquaculture development and land suitability. Those are inherent in applying good practices and appropriate environmental regulations to ensure the sustainability of aquaculture-based food production [14,71]. In improving the aquaculture environment, action plans include identifying causes of environmental quality degradation, determining quality improvement methods, and implementing improvements. In enforcing regulations, the government plays a role and influences the protection of a proper environment for the success and sustainability of whiteleg shrimp culture.

Table 6. Alternative strategies, action plans, and actors in developing intensive/super-intensive whiteleg shrimp culture in Bulukumba, Je'neponto, and Takalar Regencies, South Sulawesi Province, Indonesia.

Alternative Strategies	Action Plans	Actors
Protection of the aquaculture environment	Control of the aquaculture environment: • Determination of land suitability and carrying capacity, • Environmental quality monitoring, and • Control of aquaculture waste.	• Central government, • Provincial and local governments, and • Shrimp farmer.
	Improvement of the aquaculture environment: • Identification of causes of environmental degradation, • Determination of environmental quality improvement methods, and • Implementation of environmental improvements.	• Environmental agency, • Central government, • Provincial and local governments, and • Shrimp farmer.
Management of the aquaculture area	Preparation of spatial zoning plan for the location of the whiteleg shrimp farming business in the Regional Spatial Plan	• Central government and • Provincial and local governments.
	Disease and environmental management: • Disease control and diagnosis, • Management and implementation of aquaculture area biosecurity, • Use of WWTP pond under requirements, • Does not use toxic chemicals, and • Availability of testing laboratory.	• Fish quarantine agency, • Central government, • Provincial and local governments, and • Shrimp farmer.
	Management of culture business: • Implementation of Good Aquaculture Practices, Good Hatchery Practices, and Standard Operating Procedures, and • Application of the cropping pattern.	• Central government, • Provincial and local governments, and • Shrimp farmer.
	Institutional: • Joined farmers association, • Partnership patterns in business management, and • Increasing access to technology and information for business development.	• Financial institutions, • Shrimp farmer, • Research institute, and • University.
	Availability of facilities and infrastructure: • Availability of land suitability for aquaculture and • Availability and improvement of supporting facilities and infrastructure.	• Central government and • Provincial and local governments.
Modern technological innovation	Seed production in the hatchery: • Availability of specific pathogen-free shrimp seed and • Use of the non-ablation method on shrimp broodstock.	• Central government, • Shrimp hatchery, • Research institute, and • University.
	Shrimp production in ponds: • Engineering of the pond, • Increased use of aeration technology, • Use of automatic feeders, • Use of ultraviolet radiation in water management, • Recirculating aquaculture systems application, and • Progressive system application.	• Shrimp farmer, • Companies procuring pond facilities and infrastructure, • Research institute, and • University.

Note: Only rank 1–3 according to AHP results (Table 5).

The government has only made a few regulations, including laws, presidential decrees, presidential regulations, government regulations, ministerial decrees, and ministerial regulations, focusing on environmental management. However, socialization and supervision in enforcing these regulations still need to be improved.

After protecting the aquaculture environment, another alternative is the management of aquaculture areas. The principle is to manage whiteleg shrimp culture to minimize failure and increase productivity while remaining environmentally friendly. Suggested action plans include preparing a zoning plan for the location of the whiteleg shrimp culture business in the local spatial plans, disease and environmental management, aquaculture business management, institutions, and the availability of facilities and infrastructure. Those are related to the long-term spatial plans to (a) develop technical standardization and production automation for efficiency and increasing production, as well as (b) make and enforce regulations related to the management towards developing a more systematic culture business. With the determination of such policies, all pond activities will always be directed to the master plan. Therefore, there will be no overlapping in the making of regulations and their implementation. The delay in the government's anticipation through arrangements and regulations in the field of shrimp farming, especially in terms of safeguarding the aquatic environment through the enforcement of the Regional Spatial Planning (in Indonesia known as *Rencana Tata Ruang Wilayah* (*RTRW*), is a product that can be regarded as "the book of development" in every region, both in the provincial and regional levels and Environmental Impact Analysis (EIA) and monitoring of the aquaculture system, which has led to a continuous decline in water quality to date [72].

It is necessary to control and diagnose disease, manage and apply biosecurity in cultured areas, and use WWTP pond following the requirements. The decreased water quality causes disease attacks in the rearing pond. Several other factors include deteriorated water quality conditions in the maintenance media, leading to the development of viruses and pathogenic bacteria. Meanwhile, the shrimp's health condition will decrease in poor media. Simultaneously, disease attacks can lead to widespread mortality in shrimp populations when the disease origin is in the rearing medium and the shrimp's health declines due to stress.

WWTP ponds should be applied to minimize the waste load during rearing. The source water quality has decreased drastically due to residual feed and shrimp excrement in the production process. In intensive/super-intensive culture, whiteleg shrimp only retains a relatively small percentage of protein, most of which is disposed of in the form of excretion of feed residues and manure. However, with the WWTP ponds that meet the requirements, the water quality has met the standards for marine biota in the receiving waters [6]. The principle is to improve wastewater quality and prevent pollution of the aquatic environment. Given the importance of the WWTP ponds, the system design and capacity should have been established.

The application of GAqP, Good Hatchery Practice, and the cropping pattern is an action plan for aquaculture management. From the institutional aspect, shrimp farmers can join associations, form partnership patterns in business management, and increase access to technology and information. The availability of facilities and infrastructure should align with an action plan for suitable cultured land and supporting facilities.

To make whiteleg shrimp culture successful, the handling should start with managing the quality of the rearing media. These efforts should be directed at maintaining water quality through managing the aquatic environment with a regional approach when the culture is carried out in an aquaculture area. In developing sustainable culture, it is necessary to determine a particular location for the culture activity area by developing a supportive environment and providing sufficient land for the allotment to fulfill the long-term production target.

The management of aquaculture areas is closely related to external and internal waste management. In this case, the handling involves many parties or actors (Table 6). In its operations, efforts to suppress the negative effect of waste involve various government agencies, entrepreneurs of production facilities, and whiteleg shrimp farmers. Therefore, it is crucial to enforce government regulations to be socialized immediately. In terms of making and enforcing regulations, shrimp farmers must actively provide advice and input through the Indonesian Shrimp Farmers Association, including SCI. As consumers of these regulatory products, farmers are parties who know very well the necessary regulations. Therefore, the government only acts as a facilitator, while the initiative and driving force of all activities should be with the private sector, namely whiteleg shrimp farmers and other stakeholders.

Another alternative strategy in developing intensive/super-intensive whiteleg shrimp culture is modern technological innovation. The action plan is innovation in producing whiteleg shrimp seed through SPF availability. Furthermore, SPF seed can be ensured to be free from specific pathogens but can be infected with pathogens during culture. The seed produced from hatcheries is healthy but not necessarily free from specific pathogens. A simple innovation that can also be accomplished in shrimp hatcheries is the non-ablation method on whiteleg shrimp, which has been reported to increase the resistance to AHPND/EMS and WSD attacks [73]. Ablation causes physiological imbalance, high energy demand, alteration of biochemical pathways, and decreased hemocyanin and glucose levels in the hepatopancreas [74]. The use of whiteleg shrimp seed from non-ablated broodstock is a holistic management and biosecurity strategy that can increase pond productivity during disease outbreaks without using expensive costs or treatments. Innovations that can be made include engineering aquaculture ponds, expanding aeration technology, using automatic feeders, ultraviolet radiation in water management, applying recirculating aquaculture systems (RAS), and applying progressive systems.

Sludge is an accumulation of organic matter that settles at the bottom of the pond in intensive/super-intensive whiteleg shrimp culture. It forms an area with anaerobic conditions without oxygen. This condition is dominated by decomposing bacteria, where the uncontrolled population will cause high levels of ammonia, methane, and hydrogen sulfide. These compounds are harmful to whiteleg shrimp cultured in ponds. Conditions can be more severe when vibrios increase in the sludge, which can cause disease. Research has shown that pathogenic bacteria—one of which is vibrio—in the whiteleg shrimp's digestive tract tend to have a similar composition to the bacteria in the sludge. Those are caused by a habit of eating organic matter at the bottom. A paddle wheel is needed to direct or collect sludge to the pond's disposal point (middle or edge). Many shrimp farmers place special sections to collect sludge in the center and at the pond's edge. Generally, the collection site is rated in the middle of the pond or is called central drainage [75] or a shrimp toilet [9]. However, the design of central drainage in whiteleg shrimp culture is still very varied. The drainage area that functions as a shrimp toilet should be sloping with an area of 5–7% and a depth of 0.5–1.0 m [75]. Moreover, engineering a square-shaped culture pond results in a more effective paddle wheel for collecting sludge into the main drainage.

Using a properly engineered rearing pond system can support the life of high-density whiteleg shrimp and reduce the effects of deteriorating environmental conditions that trigger the development of *V. parahaemolyticus*, which causes AHPND/EMS disease. The application of central drainage is one of the treatises issued by FAO [70] and the application two-step culture system (nursery–grow-out) is related to strategies for preventing and handling AHPND/EMS disease.

Due to the high stocking density, an aerator as a supplier of dissolved oxygen is necessary. The types of aerators used are paddle wheels, jet aerators, and root blowers as essential aeration suppliers. Even though aeration has become a common practice in aquaculture, aerators that efficiently transfer oxygen into the water with excellent mechanical capabilities have been developed. However, knowledge about the efficient use of aerators contributing to sustainable production systems is still underdeveloped [76]. The placement of aerators is also an opportunity for additional research.

Furthermore, water depth is significant because the aerator should produce sufficient water circulation to prevent dissolved oxygen and temperature stratification. Paddle wheels as surface aerators are most widely used in intensive/super-intensive technology culture, and the ideal pond water depth with surface aerators is about 1.5 m. This can be performed by constantly moving water across the pond bottom to avoid dissolved oxygen and temperature stratification with temperatures in pond bottoms deeper than 1.5 m. In the absence of adequate dissolved oxygen at the pond bottom, anaerobic conditions develop in the sludge–water interface, potentially releasing toxic microbial metabolites into the pond water. Subsequently, aeration technology can be improved using a Microbubble Generator (MBG) to produce micro air bubbles with high solubility and saturation [77]. This aims to avoid a lack of dissolved oxygen at the pond bottom with water depths greater than 1.5 m. MBG degrades organic content more quickly and causes faster fish/shrimp growth [78]. According to Boyd et al. [76], combining aeration and circulating water may be more efficient in maintaining the dissolved oxygen concentration in ponds than applying aeration.

Feed is the highest operational cost in intensive/super-intensive whiteleg shrimp culture [79], and the cost incurred can reach more than 50% of the total operation. This technology saves the workforce and is more accurate and programmed because the existing instrument program regulates the operation. By using an automatic feeder, errors in the manual feeding method can be avoided. In other words, this instrument is very effective in improving feed management. Competitive behavior is reduced when all fish/shrimp are fed uniformly in all culture ponds, providing broad access to feed [80–82]. The feed can be given continuously; hence, the product stocked with this instrument is directly eaten in a fresh condition, and the waste can be reduced. Other impacts are also expected to reduce the feed conversion ratio (FCR) and make water quality management easier in ponds. Using automatic feeders increases shrimp culture efficiency and profits [83,84]. Control of feeding through automatic feeders will directly reduce the discharge of feed waste into the waters. However, it raises the need to improve the physical quality of the feed.

Water from the pond has an excellent opportunity to carry pathogenic viruses and bacteria into shrimp ponds through the intake system, which can impact the incidence of disease attacks. It contributes significantly to AHPND/EMS contamination in whiteleg shrimp ponds [85,86]. This disease can be avoided with preventive efforts by creating a sterile environment from the source of the disease and sterilizing the pond before stocking the seed. Pond water is also expected to be free from chemicals that can interfere with metabolism and growth. Using chemicals to eradicate bacteria and viruses often leaves residues of these substances. Therefore, it is necessary to sterilize this water without using chemicals that pose a bad risk to the health of whiteleg shrimp. In addition, the use of ultraviolet radiation as a disinfectant has developed in various aspects of life, such as health, food and beverages, swimming pool water sterilization systems, and wastewater sterilization in hatcheries. Sterilization technology using ultraviolet radiation has been proven to kill bacteria and viruses in pond water on a laboratory scale [87] and has been applied by whiteleg shrimp intensive culture in Bulukumba Regency. The use of ultraviolet radiation is a physical process of transferring electromagnetic energy to the cellular material of the organism. Ultraviolet radiation damages microorganism's deoxyribonucleic acid (DNA) by forming thymine dimers that prevent transcription and replication, leading to cell death [88,89]. Meanwhile, water free from bacteria and viruses will reduce the risk of disease attacks on whiteleg shrimp.

To protect whiteleg shrimp intensive/super-intensive technology against disease and environmental degradation, it is hoped that a shift to a closed-loop system—and ultimately, indoor systems—could be an option. Closed-loop systems, such as recirculating aquaculture systems RAS, represent a significant opportunity to increase the efficiency and production of whiteleg shrimp while reducing the risk of disease and pressure on the environment. Indonesia has started building a closed-loop system through whiteleg shrimp with super-intensive or supra-intensive technology [5,12,90]. Super-intensive technology whiteleg shrimp farming is generally still outdoors and, therefore, vulnerable to disease, pollution, and environmental risks. To protect shrimp ponds from environmental risks, sudden changes in water quality, and reduce the risk of disease, whiteleg shrimp ponds can gradually switch to closed indoor systems. This production method allows for increased stocking densities, full traceability of the product, and low environmental impact.

A progressive system is a multiphase aquaculture application, namely the rearing of whiteleg shrimp through two phases, including juvenile production and commercial size in rearing ponds [91,92]. Shrimp juvenile production can be carried out in tanks with a volume of 100 m^3 and a stocking density of 5000 post-larvae (PL) 10–12/m^3 for 21 days. The use of whiteleg shrimp is also included in the treatise related to the AHPND/EMS prevention and treatment strategy issued by FAO [70]. Furthermore, ponds are facilities with high biosecurity for growing seeds from hatcheries. Containers smaller than rearing ponds can also minimize the risk of pathogen entry, control feeding, and accumulate organic matter that triggers vibrio growth. Therefore, productivity and overall quality can be improved, including size uniformity. Rearing ponds reduces the risk of the critical culture period, which usually occurs for 30 to 50 days [91]. Disease attacks such as AHPND/EMS in critical periods can be minimized by implementing a progressive system, and the effective stocking density of shrimp using fingerlings promotes feed efficiency. The application of smart technology has become a trend in shrimp culture and feed quality management to achieve aquaculture sustainability through (a) real-time monitoring of water quality variables and aquaculture processes and (b) the use of automation to produce optimal culture processes [93].

The application of these various innovations is expected to increase the productivity of ponds and the efficiency of the management. Research institutes and universities have almost the same role: they are responsible for research activities to develop modern technological innovations for hatchery and rearing whiteleg shrimp.

4. Conclusions and Recommendations

Only 1 of the 18 intensive/super-intensive whiteleg shrimp culture businesses operating in Bulukumba, Je'neponto, and Takalar Regencies applies super-intensive technology, namely a pond located in Mangarabombang sub-district, Takalar Regency. The main problem in the whiteleg shrimp culture with intensive/super-intensive technology is disease attack, namely acute hepatopancreatic necrosis disease (AHPND) or EMS (early mortality syndrome (EMS) and white feces disease (WFD). Environmental criteria are the most influential factors in developing intensive/super-intensive whiteleg culture. Furthermore, among the seven alternative strategies, the order of priority sequentially is protecting the aquaculture environment, managing the aquaculture area, modern technological innovation, environmentally friendly technology, easy access to business and capital, improvement of human resources, and availability of pond facilities.

The stocking density in intensive technology can be increased up to 300 ind./m^2 with a pond area greater than 2000 m^2 and 500 ind./m^2 on a pond area smaller than 2000 m^2. The increase can also be performed on super-intensive technology greater than 1000 ind./m^2. Factors determining the land suitability and carrying capacity for intensive/super-intensive whiteleg shrimp culture are construction potential, soil conditions, water quality, climate, infrastructure availability, and socio-economic and legality. As a medium-term program, research institutes and universities can evaluate the land suitability and carrying capacity by considering the directions from the central, provincial, and local governments related to Regional Spatial Plan. A wastewater treatment plant pond can be used, which consists of sedimentation, aeration, and equalization plots with a volume of about 30% and 20% in the rearing pond with super-intensive and intensive technologies. It can also be performed in the rearing ponds equipped with major drainage and an area of about 5% with a depth of about 0.5 m. It should use specific pathogen free seed, or at least seed in the high health category produced using broodstock with the non-eye ablation method. Before being stocked in rearing ponds, shrimp are reared in a tank with a stocking density of 5000 PL10–12/m^3 for 14 to 21 days.

Considering that the main problems in the whiteleg shrimp culture are disease attacks, especially AHPND/EMS and WFD, the management strategies are pond expanses equipped with good biosecurity, adjustment of the capacity of the reservoir to the water volume of rearing pond, sterilization of media water by minimizing treatment using chemicals, such as ultraviolet radiation, stocking quality seed and implementing a progressive system, using an automatic feeder, the application of RAS, and the application of probiotics according to the dose and type.

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