

Spatial Integration Modeling for the Development of Blue Economy–Based Aquaculture Investment in Central Sulawesi Province

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ABSTRACT

Introduction: The development of aquaculture in Central Sulawesi requires a development framework that is not only oriented toward increasing output but also integrates economic, ecological, and social dimensions. From a Blue Economy perspective, investment is understood not simply as an increase in capital but as a transformational instrument that encourages efficiency, low-waste innovation, ecosystem protection, and social benefits for coastal communities.

Objectives: This research combines aquaculture and blue economy activities through a spatial integration approach to develop a policy to improve the regional economy in Central Sulawesi Province. This research focuses on analyzing the ability of spatial integration to identify and map aquaculture potential, enabling the application of the blue economy concept to provide a multiplier effect on regional economic development.

Methods: The basic method in this research is a descriptive explanation using a mixed-methods approach combining qualitative and quantitative research. This research method is based on the fact that, to reveal the processes driving the integration of aquaculture conditions, spatial variables must be quantified using exogenous and endogenous variables and, in the formulation of strategies, explained in depth using a qualitative approach.

Results: The R-square result for the Aquaculture Production variable is 0.796, and the R-square value for the Blue Economy-Based Aquaculture Investment variable is 0.561. The R-square value of 0.796 indicates that the variables of spatial integration, environmental carrying capacity, governance, and blue economy-based fisheries investment explain 79.6% of the variation in the aquaculture production variable, while other variables outside this research model explain the remaining 20.4%. Meanwhile, the R-square value of 0.561 indicates that spatial integration, environmental carrying capacity, and governance can explain 56.1% of the variations in blue economy-based investment.

Conclusions: Based on the results of descriptive analysis, synthesis of stakeholder interviews, and testing of the structural model using SEM-PLS, the following key findings were obtained. Spatial integration has a positive and significant effect on aquaculture production. Regional accessibility, integrated logistics infrastructure, and synchronized spatial planning have been shown to increase supply chain efficiency and support productivity gains in the coastal areas of Central Sulawesi. Environmental carrying capacity has a positive and significant effect on aquaculture production. Water quality, ecological capacity, and the control of pressures arising from aquaculture activities are important determinants in maintaining ecosystem stability, thereby enabling increased production.

Keywords *Integration Modeling, Development, Aquaculture*

INTRODUCTION:

Background

In principle, regional development requires the simultaneous achievement of two main objectives:

economic growth and the equitable distribution of development outcomes. Economic growth that is not accompanied by equity has the potential to widen social and spatial disparities, both among social groups and across regions, thereby giving rise to socio-economic vulnerabilities that can hinder the sustainability of

development [1], [2]. In the context of national development, issues of inequality and equitable development have also become important concerns, as disparities in access to infrastructure, public services, and economic opportunities among regions can influence regional capacity to achieve inclusive welfare. Interregional development disparities, particularly between growth centers and coastal or rural areas, are often reflected in differences in infrastructure quality, market access, and the availability of basic services, which ultimately affect local economic productivity and competitiveness [3], [4]

At a macro level, the agricultural sector, in a broader definition, including fisheries, continues to play an important role in the economic structure of Central Sulawesi, both as a source of livelihoods for the community and as a contributor to Gross Regional Domestic Product (GRDP) [5], [6]. However, the growth dynamics across agricultural subsectors are not uniform. The growth rate of GRDP in the agricultural sector has been slowing, while the fisheries subsector has shown an increasing trend during the most recent observation period. This overview can be seen in the following table:

Table 1. Growth Rate of GRDP of the Agricultural Sector and Subsectors at Constant Prices (ADHK) in Central Sulawesi Province, 2022–2023 (Percent)

No	Sector / Subsector	2022	2023
1	Agriculture, Livestock, Hunting, and Agricultural Services	376	2.25
	a. Food Crops	-0.22	-0.18
	b. Horticultural Crops	2.45	1.78
	c. Plantation Crops	4.98	3.01
	d. Livestock	4.79	2.05
	e. Agricultural Services and Hunting	5.72	3.82
2	Forestry and Logging	-4.81	-5.31
3	Fisheries	0.81	1.51
	Agriculture (total)	2.75	1.73

Source: Statistics Indonesia of Central Sulawesi Province, 2024

Table 1 shows that the growth rate of GRDP at constant prices (ADHK) of the agricultural sector (total) slowed from 2.75 percent in 2022 to 1.73 percent in 2023, while the fisheries subsector instead increased from 0.81 percent in 2022 to 1.51 percent in 2023. This pattern indicates that the fisheries subsector has potential as a relatively more prospective source of growth amid the slowdown of other subsectors, although its growth rate remains moderate. In addition to growth, the contribution of each sector or subsector to GRDP is important for showing its structural significance.

Building on these macro and sectoral conditions, the development of aquaculture in Central Sulawesi requires a development framework that is not only oriented toward increasing output, but also integratively combines economic, ecological, and social dimensions [7], [8]. From a Blue Economy perspective, investment is understood not merely as an addition of capital, but as a transformational instrument that promotes efficiency, low-waste innovation, ecosystem protection, and social benefits for coastal communities. Therefore, Blue Economy–based aquaculture investment becomes a key element that links increased production capacity with long-term sustainability [9], [10].

Based on the foregoing discussion, this study is important for formulating a Spatial Integration Model to develop Blue Economy–based aquaculture investment in Central Sulawesi Province. This model positions Blue Economy–based aquaculture investment as a key mechanism that transforms spatial potential, environmental quality, and governance capacity into improved production performance. This study is expected to provide empirical and conceptual contributions to the formulation of policies for productive, competitive, inclusive, and socially and ecologically sustainable aquaculture development in Central Sulawesi Province.

Problem Formulation

The essence of economic development is fundamentally a planned process aimed at realizing a society that is just, prosperous, and well-being-oriented. This development process is expected to improve the quality of life, living standards, income levels, and strengthen the quality of natural resources and environmental management. Within the framework of regional development, success is not only measured by economic growth, but also by regions' capacity to manage economic potential in a productive, inclusive, and sustainable manner, particularly in sectors that underpin community livelihoods.

Central Sulawesi Province has a large and diverse potential for aquatic resources, so the marine and fisheries

sector, particularly aquaculture, has the opportunity to become a base sector that supports the strengthening of the regional economy [11], [12]. However, the development of aquaculture is not solely determined by resource availability. Increases in production and value added in aquaculture require systemic support from upstream to downstream, including the availability of production inputs, connectivity and logistics, spatial certainty, infrastructure support, technology utilization, and the strengthening of business actor capacity [13], [14]. Thus, the agenda for aquaculture development at the provincial scale demands a coordinated, integrated approach across regions.

In this context, the Blue Economy approach becomes relevant because it emphasizes a balance between the utilization of aquatic resources and environmental conservation, while simultaneously promoting efficiency, innovation, and increased social benefits for communities [15], [16]. This approach requires the development of management systems that are capable of ensuring that production increases are not achieved at the expense of aquatic environmental quality. In other words, development policies for the aquaculture sector need to be directed toward practices that are sustainable, adaptive to ecological carrying capacity, and capable of generating long-term value added [17], [18].

Based on the foregoing discussion, the development of aquaculture in Central Sulawesi Province requires an analytical framework that explains the relationship between structural and institutional factors and improvements in production, through Blue Economy–based investment mechanisms. Specifically, spatial integration becomes important to ensure regional connectivity, logistics efficiency, and spatial certainty for aquaculture; environmental carrying capacity serves as an ecological limit and a prerequisite for production sustainability; and governance determines the quality of regulation, coordination, participation, and supervision that shape the investment climate. Accordingly, this study is focused on addressing the following questions:

Does spatial integration have a positive and significant effect on the optimization of increasing aquaculture production in Central Sulawesi Province?

Does environmental carrying capacity have a positive and significant effect on the optimization of increasing aquaculture production in Central Sulawesi Province?

Does governance have a positive and significant effect on the optimization of increasing aquaculture production in Central Sulawesi Province?

Does Blue Economy–based aquaculture investment have a positive and significant effect on the optimization of increasing aquaculture production in Central Sulawesi Province?

How does Blue Economy–based aquaculture investment act as a mediator in the effect of spatial integration on the optimization of increasing aquaculture production in Central Sulawesi Province?

How does Blue Economy–based aquaculture investment act as a mediator in the effect of environmental carrying capacity on the optimization of increasing aquaculture production in Central Sulawesi Province?

How does Blue Economy–based aquaculture investment act as a mediator in the effect of governance on the optimization of increasing aquaculture production in Central Sulawesi Province?

Research Objectives

Based on the problem formulation and background, the objectives of this study are as follows:

To analyze the effect of spatial integration on the optimization of increasing aquaculture production in Central Sulawesi Province.

To analyze the effect of environmental carrying capacity on the optimization of increasing aquaculture production in Central Sulawesi Province.

To analyze the effect of governance on the optimization of increasing aquaculture production in Central Sulawesi Province.

To analyze the positive and significant effect of Blue Economy–based aquaculture investment on the optimization of increasing aquaculture production in Central Sulawesi Province.

To analyze the role of the Blue Economy–based aquaculture investment model as a mediator in the effect of spatial integration on the optimization of increasing aquaculture production in Central Sulawesi Province.

To analyze the role of the Blue Economy–based aquaculture investment model as a mediator in the effect of environmental carrying capacity on the optimization of increasing aquaculture production in Central Sulawesi Province.

To analyze the role of the Blue Economy–based aquaculture investment model as a mediator in the effect of governance on the optimization of increasing aquaculture production in Central Sulawesi Province.

Scope of the Study

In this study, the scope or limitations of the research are as follows:

Spatial integration, environmental carrying capacity, governance, and the Blue Economy contribute to aquaculture investment in the context of increasing production and developing aquaculture in Central Sulawesi Province.

The concept of regional economic investment development based on the Blue Economy in the aquaculture areas of Central Sulawesi Province.

A spatial integration model for regional economic development based on the Blue Economy in the aquaculture areas of Central Sulawesi Province.

Research Novelty

Based on previous studies, none have shown how aquaculture, through the application of the Blue Economy concept, can serve as a foundation for the management and development of a regional economy using a spatial integration approach. Accordingly, this study integrates aquaculture activities and the Blue Economy through a spatial integration approach to formulate policies that enhance the regional economy of Central Sulawesi Province.

The focus of this study is to analyze the capacity of spatial integration to identify and map aquaculture potential in the context of using the Blue Economy concept, thereby generating a multiplier effect that enhances regional economic development.

RESEARCH METHOD

Research Type

The basic method used in this study is descriptive-explanatory research with a mixed-methods approach combining qualitative and quantitative methods. This research method is based on the premise that, to reveal the processes underlying the factors that drive the variables involved in integrating aquaculture conditions and spatial variables, these factors must be quantifiable using numerical data that include both exogenous and endogenous variables. At the same time, the formulation of strategies must be explained in depth through a qualitative approach. Sugiyono [19] explains that descriptive research is intended to provide careful measurement of specific social phenomena, in which researchers develop concepts and compile facts, but do not conduct hypothesis testing. In this study, a sequential, or phased, mixed-methods strategy is used, in which qualitative data support quantitative data. Creswell (2010) explains that a sequential or phased strategy consists of procedures in which researchers seek to combine or extend findings from one method with those from another.

Place and Time of Research

This research was conducted in Central Sulawesi Province. Specifically, the study focused on aquaculture areas. The research was carried out over six months, from July to December 2023.

Population and Sample

Population

The population is a generalized area consisting of objects or subjects that possess certain qualities and characteristics determined by the researcher to be studied and subsequently used as the basis for drawing conclusions. The population in this study comprises aquaculture business actors engaged in pond aquaculture, seaweed cultivation, and pearl cultivation in the Central Sulawesi region, totaling 30,662.

Sample

The sample was purposively selected and further developed through snowball sampling. Purposive sampling was intentionally applied to obtain accurate information for the study by identifying key respondents who possess reliable information to answer the questions formulated in the research problem. Subsequently, the

sample was expanded through snowball sampling, based on the input and recommendations of the key respondents to identify additional respondents, and this procedure was continued until the researcher considered the data obtained sufficient to address all the objectives of this study. The determination of the sample size in this study employed the Slovin formula, namely:

$$n = \frac{N}{1 + Ne^2}$$

Description:

n = Sample size

N = Population size

E = Margin of error of the study (10%)

Based on the formulation above, the sample size in this study can be calculated as follows:

$$n = \frac{30,662}{(1+(30,662 \times 10\%^2))} + \frac{30,662}{(1+(30,662 \times 0.01))} + \frac{30,662}{(1+306.62)} + \frac{30,662}{307.62}$$

n = 99,67 = 100 entrepreneurs or aquaculture households

Because the calculated result is a decimal number, the sample size in this study was rounded to 100 respondents.

Types and Sources of Data

Data consist of information materials that explain the sources of the research objects in relation to the problems being investigated. Meanwhile, quantitative data are a type of data that can be directly measured or calculated, in which such data can take the form of information, indicators, or explanations expressed in numerical values or in the form of numbers [19]

Types of Data

Quantitative data are a type of data that can be calculated and directly measured as numerical variables or values [20]. In this study, quantitative data consist of processed questionnaire results from aquaculture business actors and stakeholders in Central Sulawesi Province.

Qualitative data consist of data in the form of images, tables, interview results, documentation, and observations. In this study, the qualitative data comprise information from interviews with aquaculture business actors and stakeholders in Central Sulawesi Province.

Sumber Data

Primary data are data obtained directly from data sources. In this study, primary data were obtained from aquaculture business actors, the Regional Development Planning Agency (Bappeda), the Investment and One Stop Integrated Services Office, the Marine and Fisheries Office, the Public Works and Spatial Planning Office, village heads, community leaders, cultural leaders, Community Surveillance Groups, fisheries associations, and aquaculture communities or groups.

Secondary data are data obtained from books, records, and studies or documents collected to support primary data. Secondary data in this study include cultural records or

journal documents, laws and regulations, reports, bulletins, Statistics Indonesia (BPS), and planning documents.

Structural Equation Modeling (SEM) Analysis and Hypothesis Testing

Hypothesis testing in this study was conducted using the Structural Equation Modeling (SEM) approach with the Partial Least Squares (PLS) software. Zuhdi et al. [21] explain that structural equation modeling (SEM) is a confirmatory method that provides a comprehensive means to assess and modify both measurement models and structural models. This method can evaluate the unidimensionality, validity, and reliability of a measurement model.

The objective of PLS is to assist researchers in achieving predictive purposes. Its formal model defines latent variables as linear aggregates of their indicators. The weight estimates used to construct latent-variable component scores are determined by how the inner model (the structural model that links latent variables) and the outer model (the measurement model that represents the relationships between indicators and their constructs) are specified. As a result, the residual variance of the dependent variables (both latent and indicator variables) is minimized. Model evaluation in SmartPLS is divided into two components, namely the outer model and the inner model [22]

Assessing the Outer Model or Measurement Model

There are three criteria for assessing the outer model, namely Convergent Validity, Discriminant Validity, and Composite Reliability. Convergent validity of the measurement model with reflective indicators is assessed by correlating item or component scores obtained using PLS. Individual reflective measures are considered high if they correlate above 0.70 with the construct being measured (Duryadi, 2021). For research at the initial stage of measurement scale development, loading values ranging from 0.6 to 0.7 are considered sufficiently acceptable

Assessing the Inner Model or Structural Model

The evaluation of the inner model or structural model was conducted to examine the relationships among constructs, the significance values, and the R-square of the research model. A hypothesis can be accepted or rejected based on p-values. The level of significance applied in this study is 5%. The basis for decision-making is that a p-value ≤ 0.05 indicates acceptance of the hypothesis, whereas a p-value ≥ 0.05 indicates rejection of the hypothesis (Duryadi, 2021).

Research Stages

The research design can be interpreted as the entire sequence of processes required, from planning, implementation, and evaluation. Therefore, the process design for this study is presented in Figure 3.1 below.

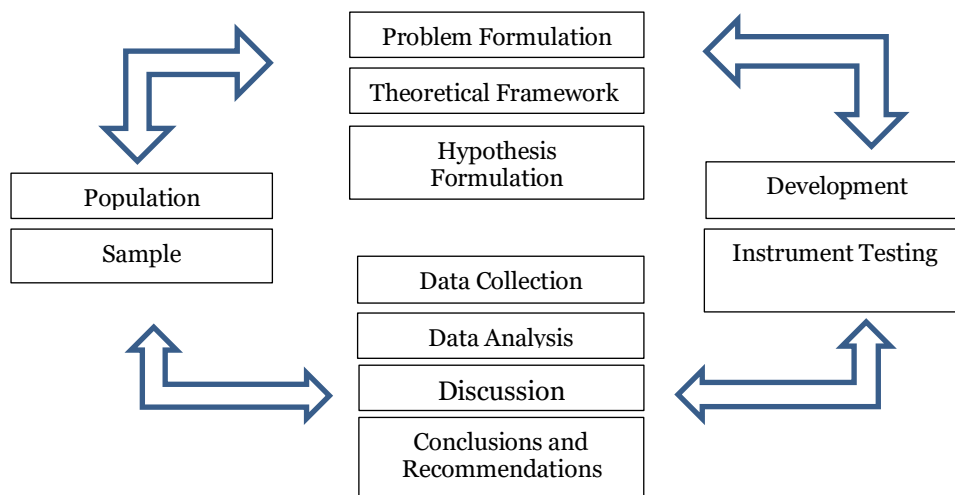


Figure 1. Research Process Stages

Based on Figure 1 above, the research stages are outlined, starting with problem formulation supported by a theoretical framework and delimited by the research objectives. The next step is to present the formulation of hypotheses as provisional answers to the research problems, which will then be verified through empirical evidence in the field. Data collection is carried out based on the size of the population and the sample when the population size is considered large.

Validity and reliability tests are conducted to determine the instruments' validity and reliability; thus, they serve as guidelines for conducting observations and developing questionnaires. The collected data are then analyzed using statistical methods, with the results presented as graphs and frequency distribution tables. If the research hypotheses are not supported, a re-examination is carried out to identify possible errors in the theory, instruments, data collection, questions, or research objectives within the theoretical framework, and if the data validation is considered to have been fulfilled, the process proceeds to

the discussion stage and subsequently to drawing conclusions.

RESEARCH RESULTS AND DISCUSSION

Validity Testing

Validity testing using the SmartPLS software can be conducted by examining the results of convergent validity and discriminant validity tests as follows:

Convergent Validity

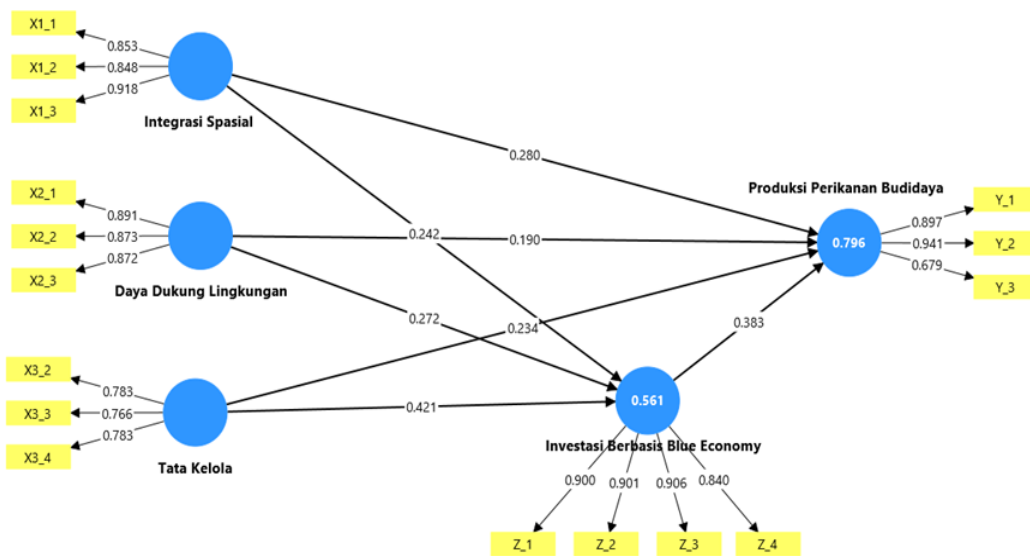


Figure 2. Results of the Outer Model Test

Source: SmartPLS Output

Based on the results of the convergent validity test shown in the figure above, the loading factor values for all indicators are > 0.50 , indicating they meet the criteria for convergent validity. Therefore, all indicators are declared valid and can be used to measure the research variables.

Discriminant Validity

Validity testing is used to determine whether a questionnaire is valid. A questionnaire is considered valid if the statements in the questionnaire are able to reveal what is intended to be measured by the questionnaire. Convergent validity testing in PLS with reflective indicators is assessed based on the value of the average variance extracted (AVE). Convergent validity is fulfilled when the component scores correlate with the construct being measured at a level greater than 0.7, or in other words, when the loading factor value is > 0.50 and significant at a level of < 0.05 . An indicator is considered to meet convergent validity in a good category when the loading factor value is > 0.5 [21], [23]

Discriminant validity is assessed by examining cross-loadings between indicators and constructs, and by assessing whether each construct predicts its indicators better than other constructs. Discriminant validity is fulfilled when the AVE value is > 0.50 (Latan & Ghozali, 2014). The AVE values can be seen in the following table:

Table 2. Average Variant Extracted (AVE)

Variable	AVE Value	Rule of thumb	Description
Spatial Integration (X ₁)	0.763	> 0.60	Valid
Environmental Carrying Capacity (X ₂)	0.772	> 0.60	Valid
Governance (X ₃)	0.604	> 0.60	Valid
Blue Economy–Based Aquaculture Investment (Z)	0.787	> 0.60	Valid
Aquaculture Production (Y)	0.718	> 0.60	Valid

Source: smartPLS output, 2025.

Table 2 above shows that the AVE values for each variable are > 0.50 . Accordingly, each variable in this

study meets the criteria for convergent validity.

Reliability Testing

Reliability testing in this study aims to measure a questionnaire that serves as an indicator of the variables. A questionnaire is considered reliable if a respondent's answers to the statements are consistent or stable over time. Construct reliability can be measured using two criteria: composite reliability and Cronbach's alpha.

Composite reliability is assessed by examining the output from the latent variable coefficients view. A construct is declared reliable if it shows a composite reliability value greater than 0.70. The results of the composite reliability testing in this study are presented as follows:

Composite Reliability

Table 3. Composite Reliability Coefficients

Variable	Composite Reliability Value	Rule of thumb	Description
Spatial Integration (X ₁)	0.906	> 0.70	Reliable
Environmental Carrying Capacity (X ₂)	0.910	> 0.70	Reliable
Governance (X ₃)	0.821	> 0.70	Reliable
Blue Economy–Based Aquaculture Investment (Z)	0.937	> 0.70	Reliable
Aquaculture Production (Y)	0.882	> 0.70	Reliable

Source: smartPLS output, 2025

Based on the test results presented in Table 3 above, the composite reliability for each variable is > 0.70. Accordingly, all variables in this study meet the criteria for composite reliability.

Reliability testing using composite reliability can be strengthened by using Cronbach's alpha values. A variable can be declared reliable or as meeting the Cronbach's alpha criterion if it has a Cronbach's alpha value > 0.6. The Cronbach's alpha values can be seen in the following table:

Cronbach's Alpha

Table 4. Cronbach Alpha Coefficients

Variable	Nilai Cronbach's Alpha	Rule of thumb	Description
Spatial Integration (X ₁)	0.846	> 0.60	Reliable
Environmental Carrying Capacity (X ₂)	0.853	> 0.60	Reliable
Governance (X ₃)	0.677	> 0.60	Reliable
Blue Economy–Based Aquaculture Investment (Z)	0.909	> 0.60	Reliable
Aquaculture Production (Y)	0.798	> 0.60	Reliable

Source: smartPLS output, 2025

Based on Table 4 above, it can be observed that the Cronbach's alpha values for each variable are greater than 0.60. Accordingly, based on the results of composite reliability and Cronbach's alpha testing, it can be concluded that all variables in this study have met the reliability criteria.

Inner model testing represents a structural model used to predict causal relationships among variables. Goodness-of-fit in PLS is assessed by examining the R-square value. The evaluation of the structural model uses R-square to assess the dependent construct, t-tests to assess the significance of the structural path coefficients. The higher the R Square value, the better the model can be considered. The results of the structural model (inner model) evaluation in this study can be seen in the following figure:

Results of Inner Model (Structural Model) Testing

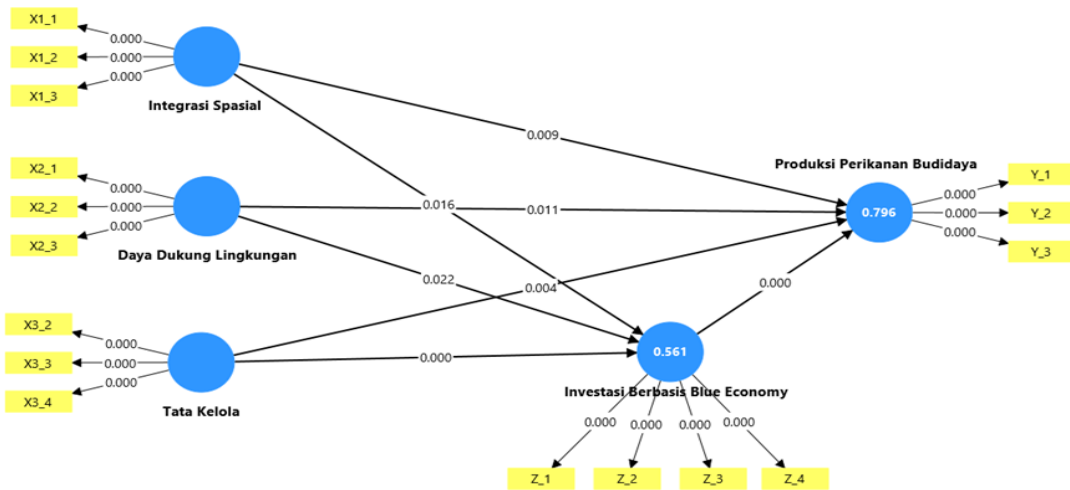


Figure 3. Inner Model

Source: Data processed using SmartPLS

Based on Figure 3, the R-square value for the Aquaculture Production variable is 0.796, and the R-square value for the Blue Economy–Based Aquaculture Investment variable is 0.561. An R-square value of 0.796 indicates that spatial integration, environmental carrying capacity, governance, and Blue Economy–based aquaculture investment explain 79.6% of the variation in the aquaculture production variable, while other variables outside the scope of this research model explain the remaining 20.4%. Meanwhile, an R-square value of 0.561 indicates that spatial integration, environmental carrying capacity, and governance explain 56.1% of the variation in Blue Economy–based investment.

Hypothesis testing in SEM-PLS is conducted using p-values and t-statistics obtained through the bootstrapping process. The basis for decision making refers to a significance level (α) of 5%, such that a hypothesis is accepted if the p-value ≤ 0.05 and rejected if the p-value > 0.05 . In addition to using p-values, decisions can also be based on t-statistic values; with a research sample size of 100 respondents, the t-table value for a one-tailed test at a 5% significance level is 1.66. Accordingly, a hypothesis is accepted if the t-statistic ≥ 1.66 and rejected if the t-statistic < 1.66 . These two criteria are applied in parallel to ensure that the relationships among latent variables tested in the structural model are statistically significant.

Hypothesis Testing

Table 5. Path Coefficients

Hipotesis	Relationship between Constructs	Path (b)	Coefficient	T Statistics (O/SDEV) (t)	p-values	Description
H1	X1→Y	0.280		2.612	0.009	Accepted
H2	X2→Y	0.190		2.548	0.011	Accepted
H3	X3→Y	0.234		2.905	0.004	Accepted
H4	Z→Y	0.383		4.471	0.000	Accepted
H5	X1→Z→Y	0.093		2.297	0.022	Accepted
H6	X2→Z→Y	0.104		1.975	0.049	Accepted
H7	X3→Z→Y	0.161		3.417	0.001	Accepted

Source: SmartPLS Output (Appendix 4), 2025

Based on the results of the path coefficient test in Table 5, the hypotheses in this study can be explained as follows:

The test results indicate that spatial integration (X₁) has a positive and significant effect on aquaculture production (Y), with a path coefficient (β) value of 0.280, a t-statistic of 2.612, and a p-value of 0.009 (< 0.05). This finding indicates that improvements in regional accessibility, the integration of infrastructure and logistics, and the

synchronization of spatial planning and zoning make a tangible contribution to optimizing aquaculture production. Therefore, the first hypothesis is accepted.

The environmental carrying capacity variable (X₂) is proven to have a positive and significant effect on production (Y), with $\beta = 0.190$, t-statistic = 2.548, and p-value = 0.011 (< 0.05). This indicates that well-maintained water quality, adequate ecological capacity, and controlled pressures from aquaculture activities are

important for increasing aquaculture production. Accordingly, the second hypothesis is accepted.

The governance variable (X_3) has a positive and significant effect on aquaculture production (Y), as indicated by a β value of 0.234, a t-statistic of 2.905, and a p-value of 0.004 (<0.05). This finding indicates that institutional and policy effectiveness, cross-sectoral coordination, public participation and transparency, as well as good compliance and environmental oversight, contribute to promoting increased production. Accordingly, the third hypothesis is accepted.

The variable of Blue Economy–based aquaculture investment (Z) shows a positive and significant effect on aquaculture production (Y), with the highest path coefficient (β) value of 0.383, a t-statistic of 4.471, and a p-value of 0.000 (<0.05). These results confirm that investment is the dominant factor in increasing production, followed by other variables, particularly increased capital and financing, the use of environmentally friendly technologies, the strengthening of production infrastructure, and the implementation of Blue Economy principles. Therefore, the fourth hypothesis is accepted.

The mediation test results indicate that Blue Economy–based aquaculture investment (Z) positively and significantly mediates the effect of spatial integration (X_1) on aquaculture production (Y), with an indirect effect coefficient (β indirect) of 0.093, a t-statistic of 2.297, and a p-value of 0.022 (<0.05). This finding shows that better spatial integration encourages greater investment, which, in turn, enhances aquaculture production. Therefore, the fifth hypothesis is accepted.

The mediation of the investment variable (Z) is also proven to be significant in the relationship between environmental carrying capacity (X_2) and production (Y), with an indirect effect coefficient (β indirect) of 0.104, a t-statistic of 1.975, and a p-value of 0.049 (<0.05). This indicates that better environmental conditions create a more conducive climate for investment, and that increased investment subsequently contributes to higher aquaculture production. Therefore, hypothesis H6 is accepted.

The test results show that Blue Economy–based aquaculture investment (Z) acts as a positive and significant mediator in the relationship between governance (X_3) and aquaculture production (Y), with an indirect effect coefficient (β indirect) of 0.161, a t-statistic of 3.417, and a p-value of 0.001 (<0.05). This finding confirms that strong, effective governance can create a more conducive investment climate, thereby increasing aquaculture production. Accordingly, the seventh hypothesis is accepted.

DISCUSSION

Based on descriptive analysis and structural model testing using the Partial Least Squares (PLS) approach, empirical findings were obtained that provide a comprehensive overview of the relationships among variables in the Blue Economy–based aquaculture investment development model in Central Sulawesi Province. Accordingly, the discussion of this study can be elaborated as follows:

The Effect of Spatial Integration on the Optimization of Increasing Aquaculture Production in Central Sulawesi Province

The results of the hypothesis test indicate that spatial integration has a positive and significant effect on increases in aquaculture production in Central Sulawesi Province. This finding reinforces the idea that coastal spatial structure, regional accessibility, and the quality of logistics infrastructure are factors that directly determine aquaculture production performance in this province. Given the regional characteristics consisting of an extensive coastline and an archipelagic configuration, aquaculture production is highly dependent on the smooth flow of inputs and the ease of distributing harvest outputs. When spatial integration improves, aquaculture activities become more efficient, technical risks decrease, and production output increases.

Respondent profiles further strengthen the understanding of the mechanisms underlying this relationship. The majority of aquaculture producers are in productive age groups (41–50 years and >50 years), with education levels predominantly at senior high school or vocational high school, and at junior high school. The cultivated commodities are also diverse, including milkfish, tilapia, grouper, catfish, vannamei shrimp, seaweed, and pearls, each with different logistics access requirements. With 42% of respondents managing land areas of 10–30 ha and 40% managing areas above 30 ha (generally intensive ponds), spatial integration becomes highly important because larger-scale operations require more regular supplies of feed, seed, and equipment, as well as rapid distribution of harvests. In addition, marketing destination data show that 38% of respondents market their products outside the province and 19% target export markets (particularly shrimp), highlighting the importance of interregional connectivity and port access.

Overall, these findings provide empirical evidence that spatial integration constitutes a structural foundation for increasing aquaculture production in Central Sulawesi. By strengthening regional connectivity, ensuring the integration of logistics infrastructure, and synchronizing coastal spatial planning, aquaculture activities can be carried out more efficiently, adaptively, and sustainably. In the context of an archipelagic province facing accessibility challenges, such as Central Sulawesi, spatial integration not only enhances production but also serves as a regional development strategy that supports blue economic growth, reduces coastal poverty, and promotes ecosystem sustainability.

The Effect of Environmental Carrying Capacity on the Optimization of Increasing Aquaculture Production in Central Sulawesi Province

Environmental carrying capacity has a positive and significant effect on optimizing aquaculture production in Central Sulawesi Province, indicating that the ecological conditions of coastal waters, including water quality, ecological capacity, and the level of pressure from aquaculture activities, play a fundamental role in

determining the success of aquaculture. As most aquaculture centers are located in sensitive bay and coastal ecosystems such as Tomini Bay, Tolo Bay, and Banggai, environmental preservation is a prerequisite for achieving stable, sustainable productivity.

Respondents provided relatively positive assessments of the quality of the aquatic environment, particularly regarding basic parameters such as pH, dissolved oxygen, and salinity, which remain within suitable ranges for fish, shrimp, and seaweed. Nevertheless, there are indications of low government supervision over the intensity of aquaculture activities, as reflected in the lowest scores on this indicator. This condition is consistent with interview findings from the Environmental Agency and the Marine and Fisheries Office, which highlight limitations in laboratory facilities, a shortage of supervisory personnel, and irregular implementation of water quality monitoring. These constraints indicate that although environmental conditions remain supportive, the monitoring system has not yet been fully optimized.

The results of this study provide empirical support for the view that the success of aquaculture is highly dependent on environmental quality and the ecological capacity of waters. From a regional development perspective, maintaining environmental carrying capacity means safeguarding the sustainability of a leading sector that provides income for coastal communities and contributes significantly to the regional economy. Accordingly, efforts to strengthen water quality monitoring systems, enhance compliance among business actors, improve supervisory infrastructure, and implement sustainable aquaculture practices constitute strategic agendas to ensure that production increases remain within the corridor of ecological sustainability.

The Effect of Governance on the Optimization of Increasing Aquaculture Production in Central Sulawesi Province

The results of the statistical testing indicate that governance has a positive and significant effect on increases in aquaculture production in Central Sulawesi Province. This finding reinforces that institutional effectiveness, regulatory certainty, cross-sector coordination, community involvement, and environmental supervision constitute essential pillars that determine the quality of the aquaculture production system in coastal areas. In Central Sulawesi, characterized by archipelagic geography and dispersed aquaculture centers, the quality of governance is a key determinant of whether aquaculture activities can be carried out efficiently, adaptively, and sustainably.

Interviews with stakeholders reinforce this depiction. The Marine and Fisheries Office (DKP) and the Regional Development Planning Agency (Bappeda) emphasize that inter-agency coordination has been functioning reasonably well but still requires strengthening, particularly in integrating spatial data, synchronizing programs, and aligning land–sea spatial planning. Meanwhile, the Investment and One Stop Integrated Services Office (DPMPTSP) highlights that the OSS system has opened access to licensing processes that are

more transparent and efficient, yet spatial certainty, including the availability of land that is ready for development, remains an aspect that needs to be strengthened so that investors can operate with adequate legal certainty. Findings from the Public Works and Spatial Planning Office also indicate that overlapping spatial utilization and limited coordination continue to constitute structural constraints that affect the effectiveness of coastal management.

The results of this study provide strong evidence that governance is a strategic factor determining the success of aquaculture sector development in Central Sulawesi. Good governance creates regulatory certainty, enhances the effectiveness of coordination, strengthens environmental oversight, opens more efficient access to licensing, and expands space for community participation. This combination of factors creates an institutional ecosystem capable of driving significant increases in aquaculture production while simultaneously supporting the objectives of sustainable development and the blue economy in coastal areas.

The Effect of Blue Economy–Based Aquaculture Investment on the Optimization of Increasing Aquaculture Production in Central Sulawesi Province

The research results show that Blue Economy–based aquaculture investment has a positive and significant effect on increasing aquaculture production in Central Sulawesi Province. These results confirm that the direction of aquaculture sector development, supported by capital, technology, supporting infrastructure, and policies that favor efficiency and sustainability, directly impacts improvements in production performance at the aquaculture operator level. In the context of an archipelagic region such as Central Sulawesi, with aquaculture centers in Parigi Moutong, Banggai, and Morowali, the presence of well-planned, sustainability-oriented investment is a highly decisive factor in the effectiveness of the production system.

The Blue Economy concept views investment not only as an effort to strengthen economic capacity, but also as a means to ensure that aquaculture activities are carried out within a sound ecological framework and provide social benefits for coastal communities. When aquaculture producers gain better access to financing sources, production facilities, and environmentally friendly technologies, productivity increases because production processes become more efficient, mortality rates decline, and input–output flows are better managed. Respondents in this study confirmed that increased business capital and improved access to financing enabled them to rehabilitate ponds, use aerators, improve seed quality, and optimize feed management, which ultimately contributed to increased production [24], [25].

The positive relationship between Blue Economy–based investment and increased production indicates that investment serves as a strategic mechanism that strengthens the aquaculture sector from economic, ecological, and social perspectives. Increases in capital and technology enhance production capacity, more environmentally friendly aquaculture practices maintain

water quality and reduce the risk of harvest failure, while improved capacity of aquaculture actors promotes productivity and welfare. In Central Sulawesi, Blue Economy–based investment is a primary driver of the development of a competitive, adaptive, and sustainable aquaculture sector.

Mediation of Blue Economy–Based Aquaculture Investment in the Effect of Spatial Integration on the Optimization of Increasing Aquaculture Production in Central Sulawesi Province

The results of this study show that Blue Economy–based aquaculture investment significantly mediates the relationship between spatial integration and increased aquaculture production in Central Sulawesi Province. This finding indicates that spatial integration not only has a direct effect on increasing production but also creates structural conditions that enable investment, in terms of capital, infrastructure, and technology, to flow more optimally into aquaculture areas. In other words, effective spatial integration strengthens the investment climate, and ultimately, increased investment becomes a mechanism that drives aquaculture productivity in this province.

Interregional connectivity through transportation access, smooth distribution chains, and spatial certainty for aquaculture plays a significant role in attracting investment [26], [27]. In coastal areas of Central Sulawesi, such as Parigi Moutong and the Banggai Islands, ease of access to ports, markets, and logistics facilities becomes a factor that increases the interest of banks, cooperatives, and business actors in channeling financing and capital. Interviews with the Investment and One Stop Integrated Services Office (DPMPTSP) indicate that OSS-based integrated licensing, combined with zoning certainty within the RZWP3K framework, provides legal certainty for investors.

Thus, these findings make an important contribution by showing that spatial integration and investment are not independent but mutually reinforcing. Spatial integration creates investment opportunities, while Blue Economy–based investment strengthens the impact of spatial integration on production enhancement. The synergy between the two becomes a key driver of productive, inclusive, and sustainable aquaculture development in Central Sulawesi Province.

Mediation of Blue Economy–Based Aquaculture Investment in the Effect of Environmental Carrying Capacity on the Optimization of Increasing Aquaculture Production in Central Sulawesi Province

The results of the study indicate that Blue Economy–based aquaculture investment significantly mediates the relationship between environmental carrying capacity and the increase in aquaculture production in Central Sulawesi Province. This finding indicates that favorable aquatic environmental conditions not only provide a direct effect on productivity but also create a more attractive climate for investment [2], [28]. Furthermore, incoming investment plays a role in strengthening production quality through the adoption of technology, the enhancement of infrastructure capacity, and financial

support that encourages efficiency and the sustainability of aquaculture activities.

Central Sulawesi, particularly the Tomini Bay area, is known to have relatively good and stable water quality at several aquaculture sites for seaweed, fish, and shrimp. These supportive environmental conditions serve as an attractive factor for small- and medium-scale business actors to continuously develop their enterprises. Interview results with the Marine and Fisheries Office (DKP) and the Environmental Agency (DLH) indicate that locations with stable, unpolluted water quality and adequate ecological carrying capacity are more capable of attracting interventions in the form of capital assistance, technical guidance programs, distribution of aquaculture equipment, and the development of environmentally friendly technologies. Thus, a healthy environment functions as a pre-investment condition that makes investment feasible and profitable.

Aquaculture production in Central Sulawesi further reinforces this conclusion. The increase in production during 2023–2024 occurred concurrently with the intensification of capital assistance programs, improved availability of superior seed, and enhanced technical training, such as CBIB, which were primarily directed toward areas with good water quality. Thus, this empirical context demonstrates that environmental carrying capacity facilitates investment, and it is this investment that becomes the pathway through which environmental capacity is transformed into increased production output.

Empirically, the mediation of Blue Economy–based investment in the relationship between environmental carrying capacity and production demonstrates that sustainable aquaculture systems cannot rely solely on environmental conditions, but also require appropriate support in the form of capital, policies, and technology [29], [30]. When supportive ecological conditions are combined with targeted and environmentally friendly investment, productivity increases significantly and sustainably. In the context of coastal regional development in Central Sulawesi, this mediation mechanism indicates that maintaining environmental quality is not only an ecological obligation but also a crucial economic strategy for attracting investment and improving the performance of the aquaculture sector.

Mediation of Blue Economy–Based Aquaculture Investment in the Effect of Governance on the Optimization of Increasing Aquaculture Production in Central Sulawesi Province

The results of the study indicate that Blue Economy–based aquaculture investment significantly mediates the relationship between governance and increased aquaculture production in Central Sulawesi Province. This finding provides strategic meaning: good governance not only has a direct impact on production effectiveness but also creates an ecosystem of regulation, coordination, and legal certainty that enables investment to flow more intensively into the aquaculture sector. In other words, governance functions as an institutional prerequisite that strengthens the attractiveness of the aquaculture sector to capital and technology, and such investment becomes the

pathway that amplifies the impact of governance on productivity enhancement.

Good governance is reflected in institutional effectiveness, policy clarity, licensing transparency, interagency coordination, and compliance with environmental oversight. Stakeholders, particularly Bappeda, the Marine and Fisheries Office (DKP), the Environmental Agency (DLH), and the Investment and One Stop Integrated Services Office (DPMPTSP), emphasize that cross sector coordination such as DKP–DLH–Public Works–Spatial Planning constitutes an essential foundation to ensure that aquaculture locations comply with zoning regulations, production activities do not exceed environmental carrying capacity, and business actors obtain licensing certainty. The existence of the RZWP3K, the integration of the Spatial Plan (RTRW) through Law No. 1 of 2023, and the OSS system used in licensing are components of governance that provide policy certainty and strengthen investor confidence.

At the implementation level, better governance also establishes clear supervision mechanisms, interagency communication forums, and consultation spaces for business actors. This study finds that aquaculture producers who receive better government services, such as simplified licensing, technical assistance, and access to spatial planning information, are better able to attract both capital investment and technology. Accordingly, governance becomes an enabler that reduces transaction barriers, lowers business risks, and enhances the credibility of the aquaculture sector in the eyes of banking institutions, private investors, and the central government.

Empirical data from respondents reflect this phenomenon. Although some aquaculture producers still rely on traditional methods, those operating in areas with better governance quality tend to have stronger access to business capital, technical training, and supporting infrastructure. This is reflected in positive stakeholder perceptions regarding licensing transparency, cross-sector coordination, and the effectiveness of regional institutions in ensuring environmental protection. All of these factors strengthen the inflow of investment and ultimately have an effect on achieving more stable and efficient increases in production.

The overall findings indicate that governance is not merely a normative structure but rather a strategic catalyst for mobilizing productive investment in the Blue Economy. Strong governance provides an institutional foundation that enhances investor confidence, reduces business risk, and accelerates the adoption of technologies aligned with ecological capacity. Investment then functions as a transformation mechanism that converts governance capacity into tangible increases in production capacity. The combination of adaptive governance and Blue Economy–based investment is a key driver of inclusive, productive, and sustainable aquaculture growth in Central Sulawesi Province.

CONCLUSION AND RECOMMENDATIONS

Conclusion

This study aims to analyze the effects of spatial integration, environmental carrying capacity, and

governance on the optimization of increasing aquaculture production in Central Sulawesi Province, as well as to examine the role of Blue Economy–based aquaculture investment as a mediating variable. Based on the results of descriptive analysis, the synthesis of interviews with stakeholders, and structural model testing using SEM-PLS, several key conclusions are obtained as follows:

Spatial integration has a positive and significant effect on aquaculture production. Regional accessibility, the integration of logistics infrastructure, and the synchronization of spatial planning have been proven to increase supply chain efficiency and support productivity improvement in the coastal areas of Central Sulawesi.

Environmental carrying capacity has a positive and significant effect on aquaculture production. Water quality, ecological capacity, and the control of pressures from aquaculture activities are important determinants in maintaining ecosystem stability, thereby enabling increased production yields.

Governance also has a positive and significant effect on aquaculture production. Institutional effectiveness, cross-sector coordination, licensing transparency, and compliance with environmental oversight create a conducive business climate and strengthen the production performance of aquaculture operators.

Blue Economy–based aquaculture investment has a highly significant effect on production. Support in the form of capital, environmentally friendly technologies, supporting infrastructure, and efficient resource use accelerates productivity improvements and enhances the quality of aquaculture outcomes.

Blue Economy–based investment significantly mediates the effect of spatial integration on production. Spatial integration creates conditions conducive to the flow of investment, and this investment subsequently strengthens the impact of spatial integration on productivity improvements.

Blue Economy–based investment also mediates the relationship between environmental carrying capacity and production. A healthy environment attracts greater capital and technological interventions, thereby investing in the pathway that enhances production capacity through sustainable aquaculture practices.

Investment significantly mediates the effect of governance on production. Transparent, well-coordinated, and adaptive governance creates business certainty and investor confidence, enabling incoming investment to strengthen the production performance of the aquaculture sector.

RECOMMENDATIONS

Based on the research findings and various inputs from stakeholders, several recommendations can be proposed as follows:

Strengthening cross-sector coordination in coastal spatial management and aquaculture investment

This study shows that the effectiveness of coastal area governance is still affected by limitations in inter-agency coordination. Cross-sector forums involving the Marine

and Fisheries Office (DKP), the Environmental Agency (DLH), the Regional Development Planning Agency (Bappeda), the Public Works and Spatial Planning Office, the Transportation Office, and the Investment and One Stop Integrated Services Office (DPMPTSP) need to be strengthened so that the process of spatial data synchronization, control of spatial utilization, and integration of aquaculture development programs can be carried out in a more directed manner. Strengthening this coordination is essential to ensure that aquaculture locations align with zoning regulations and environmental carrying capacity, while also creating business certainty for both investors and aquaculture producers.

Enhancing community participation in the planning and evaluation of aquaculture programs
The low perception of community involvement indicates the need for a more inclusive approach in policy formulation and evaluation. Involving aquaculture producer groups, community leaders, and local institutions in the design of aquaculture programs will enhance policy legitimacy and improve the effectiveness of implementation in the field. Providing more transparent access to information on licensing, zoning, and environmental conditions will also strengthen community participation while encouraging the emergence of social oversight in coastal spatial management.

Strengthening environmental monitoring systems and supporting laboratory facilities

Stakeholders highlight limitations in equipment, the lack of laboratory facilities, and the shortage of supervisory human resources as major constraints in water quality monitoring. Therefore, local governments need to develop adequate aquatic laboratories, expand community-based water quality monitoring programs, and enhance the capacity of fisheries extension officers and inspectors. Strong environmental monitoring is essential, given that the carrying capacity of aquatic ecosystems constitutes the primary foundation of production and serves as a key factor in attracting sustainable investment.

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