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Research Article

Framework for Sustainable Management of Shellfish Resources Based on Eco-Biology and Socio-Economic Conditions in Sedati, Sidoarjo, Indonesia

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Abstract

Sedati is one of the subdistricts producing fishery products, namely milkfish, shrimp, and shellfish. Some of the products are further processed generate long-term income. Economic variables profoundly influence shellfish harvesting, as heightened catches immediately enhance fishermen's revenue. Nonetheless, increased income may lead to intensified fishing activities, potentially jeopardizing the viability of shellfish populations if not adequately regulated. This study develop to the framework for sustainable management of shellfish resources based on eco-biology and socio-economic conditions. This research used a survey research method with primary and secondary data. The study employed a purposive sampling method, selecting 224 fishermen from two villages, Banjar Kemuning and Gisik Cemandi, in Sedati District, Sidoarjo Regency, Indonesia. The hauling process is carried out while catching shellfish 100-150 times. Shellfish fishing activities are carried out 20–26 days a month. This study found that catch factors having no significant effect on sustainable fisheries management, ecological factors and shellfish capture and sustainable fisheries and sustainable fisheries management social factors and the capture of shellfish. Biological factors and shellfish catchment and management economic factors influence the shellfish capture showed significant influence on the fisheries management. The development of this model can serve as a benchmark for shellfish fishing activity in this coastal water. Overfishing or activities in this area can be monitored using this model. The purpose is to control or monitor the stock and the inventory of the shellfish fisheries to preserve them for further use. Economic factors have a significant effect on shellfish caching because the more shellfish caught, the income of shellfish fishermen will directly increase, economic factors also have a significant influence on the sustainable management of shellfish. The greater the income of fishermen, the greater the availability of shellfish stocks will be because the fishing effort carried out by fishermen will be massive. This research in the future can provide information on how to balance ecological, economic, and social factors to ensure the long-term viability of shellfish populations and the ecosystem support.

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1. Introduction

Sidoarjo Regency is geographically bordered by Surabaya City and Gresik Regency to the north, Pasuruan Regency to the south, the Madura Strait to the east, and Mojokerto Regency to the west (Statistics of Sidoarjo Regency, 2017). Sedati Subdistrict, known for its significant fishery products, including milkfish, shrimp, and shellfish, plays a key role in the region's economy. Some of these products are further processed, providing long-term economic benefits (Nurgaliyeva *et al*., 2024; Danilova, 2022). According to Statistics of Sidoarjo Regency data (2020), Sedati covers an area of 79.43 km², making it the second-largest sub-district in the region, with a population of 111,788 people and an annual growth rate of 1.78%.

Sedati's shellfish resources primarily include species such as Anadara (clams), Crassostrea (oysters), and Perna (mussels). These species contribute significantly to the local economy by providing a steady income for fishermen through direct sales and value-added products like processed or dried shellfish. Additionally, these shellfish serve an important ecological role as filter feeders, improving water quality by removing plankton and organic matter (Abd-El-Aziz, 2021; Khan and Liu, 2019; Wright *et al*., 2018). In Indonesia, the *Paratapes undulatus* is known as the Batik clam or the short neck clam. *Paratapes undulatus*, commonly known as the "oil clam", is an undulated surf clam with the characteristic of living in shallow seas and is a species of benthic clam (Zhang *et al*., 2019) It is typically sold and consumed in both local and international markets. Shellfish are abundant in protein and healthful fats, as well as in various micronutrients, including iron, zinc, magnesium, inorganic phosphate, sodium, potassium, selenium, iodine, and other nutrients. According to research findings (Permata *et al*., 2023), the protein content of batik shellfish is 10.34%, based on research (Joy and Chakraborty, 2017) said that the protein content of *Paratapes undulatus* shellfish is around 13-15% wet weight *Paratapes undulatus* is an edible sea shellfish consumed internationally and locally in Egypt (Mahmoud and Yassien, 2023).

Short neck clams (*batik clam*) have been a source of income for some coastal communities in Sedati District, Sidoarjo Regency, East Java Province, Indonesia for many years. Shellfish fishing in Indonesia has been recorded since 1979, with production reaching 48,926 tons/year or equivalent to a value of IDR 6.15 billion in 1984 (Tiensongrusmee and Pontjoprawiro, 1988). The volume of Indonesian shellfish production has continued to increase in the last decade, reaching an average of 94,247.1 tons/year with a value of IDR 565.48 billion/year (Ministry of Maritime Affairs and Fisheries, 2022). Based on data from the Statistics of Sidoarjo Regency (2019), the value of shellfish production in Sidoarjo in 2015 was 342,700 tons, in 2016 it was 2,329,800 tons, in 2017 it was 458,900 and in 2018 it was 5,842,400 tons. In 2018, the total production of shellfish per year in the Sedati sub-district was 4,192,000 tons. Shellfish management has provided benefits to coastal communities in the form of creating fieldwork, both as fishermen, cultivators, collectors, middlemen, and retailers (Tookwinas, 1985). Based on (Philippart *et al*., 2020) research, shellfish can provide sustainable food and income for coastal communities.

Shellfish also contribute ecological advantages to social and ecological. According to Peterson (2001), suspension-feeding bivalves, including batik clams, can reduce water turbidity through filtering activities, and economic for sustainable management. Shellfish resource management can be carried out through a collaborative approach between stakeholders, utilizing adaptive management practices, and ensuring strong monitoring and law enforcement mechanisms can support the long-term sustainability of shellfish resources and the welfare of local communities. According to Ferriss *et al*. (2022) integrating social and ecological aspects of shellfish in research and management processes can improve understanding of the system as a whole, and facilitate management decision-making. This research aims to develop to the framework for sustainable management of shellfish resources based on eco-biology and socio-economic conditions. One method to analyse it is using PLS-SEM. The overexploitation and habitat degradation of shellfish populations, threatening their sustainability and the ecological services they provide, while also impacting the communities that depend on them PLS-SEM is a statistical technique appropriate for examining intricate linkages within socio-ecological systems, rendering it optimal for investigating sustainable shellfish management. It may simulate the interactions of economic elements (e.g., fishermen's income), ecological factors (e.g., shellfish populations and habitat conditions), and social factors (e.g., community practices and rules). PLS-SEM elucidates the links between economic activity and ecological sustainability, hence informing balanced management solutions.

2. Materials and Methods

A theoretical framework is constructed based on the defined study objectives. To evaluate the hypotheses, we applied Partial Least Squares Structural Equation Modeling (PLS-SEM) using SmartPLS 3.0 software. This method was selected for its ability to model complex relationships among multiple variables and to simultaneously assess both direct and indirect effects. Data collected from the survey responses were processed to construct latent variables, which were then analyzed for path relationships among ecological, social, and economic factors influencing sustainable fisheries management. Hypotheses that pass rigorous testing will be deemed approved, whilst those that do not meet the testing criteria will be deemed rejected. Hypothesis (H) 1 = The capture of shellfish is strongly and positively impacted by biological parameters. H2 = Biological factors have a major and positive impact on Sustainable Fisheries Management. The management of sustainable fisheries is greatly and positively affected by capture factors. H4 = The collection of shellfish is greatly and favorably affected by ecological conditions. H5 = Ecological considerations have a major and positive impact on Sustainable Fisheries Management. H6 = The economic considerations have a considerable and favorable impact on the capture of shellfish. H7 = Economic variables have a major and beneficial impact on the sustainable management of fisheries. The harvesting of shellfish is greatly and positively impacted by social factors. Sustainable fisheries management is greatly and positively impacted by social factors. This hypothesis design was established based on the work of Odongtoo *et al.* (2021).

2.1 Materials

To assess sustainable shellfish management practices, PLS-SEM was employed as the primary analytical tool. This method allows for a detailed examination of the intricate relationships between socio-economic factors, such as fishermen's income, and ecological factors, including the biological conditions of shellfish populations. The proposed model is examined in two separate phases: the initial phase involves a model that establishes the connection between latent variables and manifest variables, while the subsequent phase entails a structural model that demonstrates the relationship between manifest variables. Through the process of reviewing the literature, a comprehensive total of 25 characteristics were identified and categorized as "observed variables." The elements were classified into six categories: ecological characteristics of the shellfish habitat, biological characteristics of the shellfish, economic circumstances of the fishermen, social circumstances of the fishermen, catches, and shellfish resource management. The framework for sustainable bivalve resource management is shaped by six main elements.

2.1.1 Ethical approval

This study does not require ethical approval because it does not use experimental animals.

2.2 Methods

2.2.1 Study area

The investigation was conducted in the villages of Banjar Kemuning and Gisik Cemandi Village, Sedati District, Sidoarjo Regency, East Java Province, Indonesia, from March to December 2019 (Figure 1). Utilizing survey methodologies, the investigation was conducted quantitatively. Respondent data was collected using interview techniques and a questionnaire guide.

2.2.2 Population and sample

The shellfish fishery community in Banjar Kemuning village and Gisik Cemandi village, Sedati District, Sidoarjo Regency, East Java Province, Indonesia, comprised the population of this study. The purposive sampling method was employed to determine the sample, which involves the deliberate selection of respondents who meet specific sample requirements. The respondents selected for this study are adults (aged 17 years and older) who reside in the villages of Banjar Kemuning and Gisik Cemandi Village, Sedati District, Sidoarjo Regency, East Java Province, Indonesia. They are fishermen who either pursue shellfish as their primary or secondary source of income. The number of respondents was calculated using the Slovin formula (Ridwan and Kuncoro, 2007):

$n = N / (1+N (e) ^ 2)$...(i)

Where:

N = Population

e = The percentage of inaccuracy allowance that can still be tolerated is 10%.

n = Sample area

Referring to the total number of shellfish fishermen in Sedati District was 305 people, So the number of respondents involved in this research based on calculations using the Slovin formula was 224 respondents with the distribution of respondents in the village of Gisik Cemandi as many as 106 respondents and in the village of Banjar Kemuning as many as 118 respondents.

2.2.3 Analysis data

The descriptive survey procedure was implemented in this investigation. The objective of this descriptive research is to provide a comprehensive, factual, and precise depiction, illustration, or painting of the facts, characteristics, and relationships between the phenomena under investigation (Nazir, 2005). Purposive sampling was employed to collect ecological and biological data in Sedati waters, while interviews and observation of fishermen were employed to collect socio-economic data. The respondents in this survey were selected through stratified random sampling. This sampling method is employed for populations that contain members or elements that are not homogeneous, as per Purwanto (2009). The process of structured random sampling involves the division of the population into numerous small sub-groups, or strata, and the subsequent selection of a sample from each stratum.

complex relationships. An additional benefit of SEM applications is their capacity to verify the dimensions of a concept or factor and, concurrently, quantify the degree of influence or relationship between factors whose dimensions have been identified (Ferdinand, 2014). The variables included in the analysis are determined by the model specifications, which are derived from the studies that have been conducted (Nababan and Wiyono, 2017). These variables are classified as endogenous latent variables and exogenous latent variables. According to Mattjik and Sumertajaya (2011),

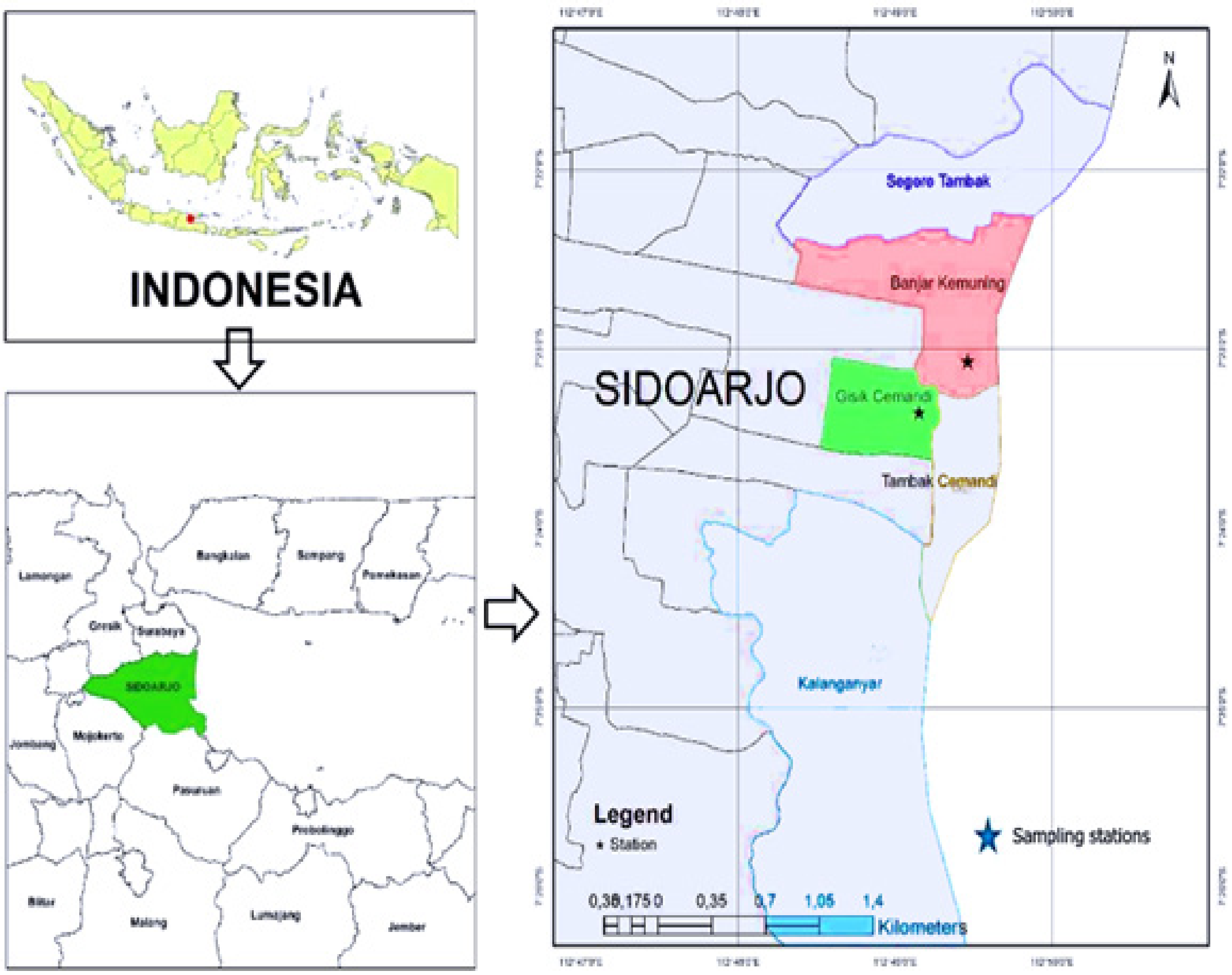

Figure 1. Research location.

The SmartPLS3 program is used to convert data on ecological, biological, social, and economic conditions to a Likert scale for further hypothesis testing. This is accomplished through the use of data analysis techniques, specifically Structural Equation Modelling (SEM). The rationale for employing SEM is that it is a collection of statistical methods that enables the simultaneous testing of a series of relatively

SEM comprises two categories of latent variables: exogenous variables, which are independent and represented by Ksi (ξ). The dependent variables in the model are endogenous variables, which are resolved by Eta (η). The research model incorporated four exogenous latent variables (ecological, biological, social, and economic factors) and two endogenous latent variables (shellfish capture and sustainable fisheries management). This model was designed to explore the relationships between these factors and evaluate their collective impact on sustainability.

3. Results and Discussion

3.1 Results

Ecological condition values included in the SEM analysis were salinity, DO, pH, temperature, and water depth, while biological values were obtained from data on distribution patterns, season length, fishing time, and selectivity of fishing gear. For social variables, values are obtained from data on age, education, experience, and fishermen's organization, while economic variables are obtained from values of Gross Income per Year Gross Revenue per Trip, Gross Revenue per Hour, Gross Revenue per Worker, and Gross Revenue per Investment Cost (X4.5). The assessment data was obtained, which is listed in variable latent and manifest (Table 1).

Table 1. Variable latent and manifest.

Latent Variable	Manifest Variable	Modus
Ecology (x1)	Salinity (X1.1)	5
	DO (X1.2)	3
	pH (X1.3)	5
	Temperature (X1.4)	5
	Water depth (X1.5)	3
Biology (x2)	Season Length (X2.1)	3
	Length of Arrest (X2.2)	3
	Fishing Gear Selectivity (X2.3)	5
Social (x3)	Age (X3.1)	3
	Education Level (X3.2)	3
	Experience (X3.3)	3
	Number of organizations (X.4)	2
Economy (x4)	Gross Income per Year (X4.1)	2
	Gross Revenue per Trip (X4.2)	2
	Gross Revenue per Hour (X4.3)	4
	Gross Revenue per Worker (X4.4)	5
	Gross Revenue per Investment Cost (X4.5)	3
Catch (y1)	Production per year (Y1.1)	1
	Production per trip (Y1.2)	2
	Production per operating hour (Y1.3)	2
	Production per worker (Y1.4)	3
	Production per investment cost (Y1.5)	5
Sustainable Management (y2)	Conditions of Diversity (y2.1)	4
	Power usage (y2.2)	5
	Fishermen's Welfare (y2.3)	3

In the PLS-SEM analysis, we first conducted a validation of the model by assessing convergent validity, discriminant validity, and reliability of the constructs. Variables with outer loadings below the threshold of 0.7 were excluded from further analysis. The final model was evaluated using both outer model (measurement model) and inner model (structural model) to ensure that the constructs were valid and reliable, as indicated by the average variance extracted (AVE) and composite reliability (CR) values. The deleted manifest variables are X1.1, X1.2, X1.5, X2.2, X2.3, X3.1, X3.2, X3.4, X4.1, Y1.1, Y1.2, Y1.4, Y1.5, Y2.1, and Y2.2, The path diagram about the model of the relationship between latent variables before and after validation is shown in Figure 2 and Figure 3.

3.1.1 Measurement model test (outer model)

The purpose of the measurement model is to illustrate the connection between constructs and their accompanying indicator variables, generally known as the outer model in PLS-SEM. The measurement model examines convergent validity, discriminant validity, and construct reliability to determine the accuracy and consistency of measuring the construct. Figure 4 depicts the external model in SmartPLS after undergoing validation.

3.1.2 Convergent validity

The validity of a reflexive indicator as a variable measure is determined by convergent validity, as evidenced by the outer loading of each variable indicator. The estimated value of the model indicates that all loading factor values are greater than 0.7, indicating that the value is valid or can be used as data in the model as a whole. Table 2 displays the outer payload value.

3.1.3 Discriminant validity

Discriminant validity refers to the extent to which a measure can distinguish between different constructs or concepts. Discriminant validity refers to the extent to which a concept can be differentiated from other concepts based on empirical evidence. Discriminant validity refers to the idea that a certain construct is unique and encompasses a reality that is not duplicated by other constructs in the model. The cross-loading between the indicator and the construct is the criterion used to assess the discriminant validity of a reflexive indicator. The correlations between all construct indicators (latent variables) and their respective indicators are higher compared to the correlations of other construct indicators (latent variables) as shown in cross-loading value (Table 3).

This illustrates that the indicators within each of the latent constructs (Ecology, Biology, Social, Economy, Capture, and Sustainable Fisheries) may be forecasted with more precision compared to the indicators in the other constructs. Based on Table 3, shows that the correlation value of indicators for one construct is higher than for other constructs. Then the cross-loading value for each construct indicator is under the recommended value, namely 0.70. These results can be concluded that the data has good discriminant validity.

3.1.4 Construct reliability

The validity test for reflective constructs assesses the extent to which the measurements of a con struct should exhibit a high level of correlation. The-loading factor values for each indicator of a construct provide an indication of the validity of reflective constructs when they are tested using reflective constructs. The standard loading factor value must adhere to a minimum threshold of 0.7, while the average extracted value (AVE) must surpass 0.5. A high loading factor indicates that the indicators inside a construct have a substantial number of similarities, leading to a common understanding within the construct (Hair *et al*., 2019). Table 4 presents the measurements of construct reliability and validity.

According to construct reliability and validity values (Table 4), the AVE value is higher than 0.5, which suggests that it is a significant factor of the proposed convergent validity, as stated by the Fornell-Larcker criteria. The value exceeded the correlation value with other constructs, as established by the Fornell-Larcker criteria. Similarly, the composite dependability rating shows a level of internal consistency that is greater than 0.6. Typically, the measuring model evaluates the relationships among the constructs (Ecology, Biology, Social, and Economy), and each indicator value meets the prescribed criterion standards. Put simply, the relationship between the constructs and the indicators can be utilized in the pre-existing modeling.

Based on the information provided, if the outer loading is higher than 0.4 and above the average variance extracted (AVE) value, we can conclude that all indicators meet the rule of thumb. Hence, there is no need to eradicate signs and reassess them.

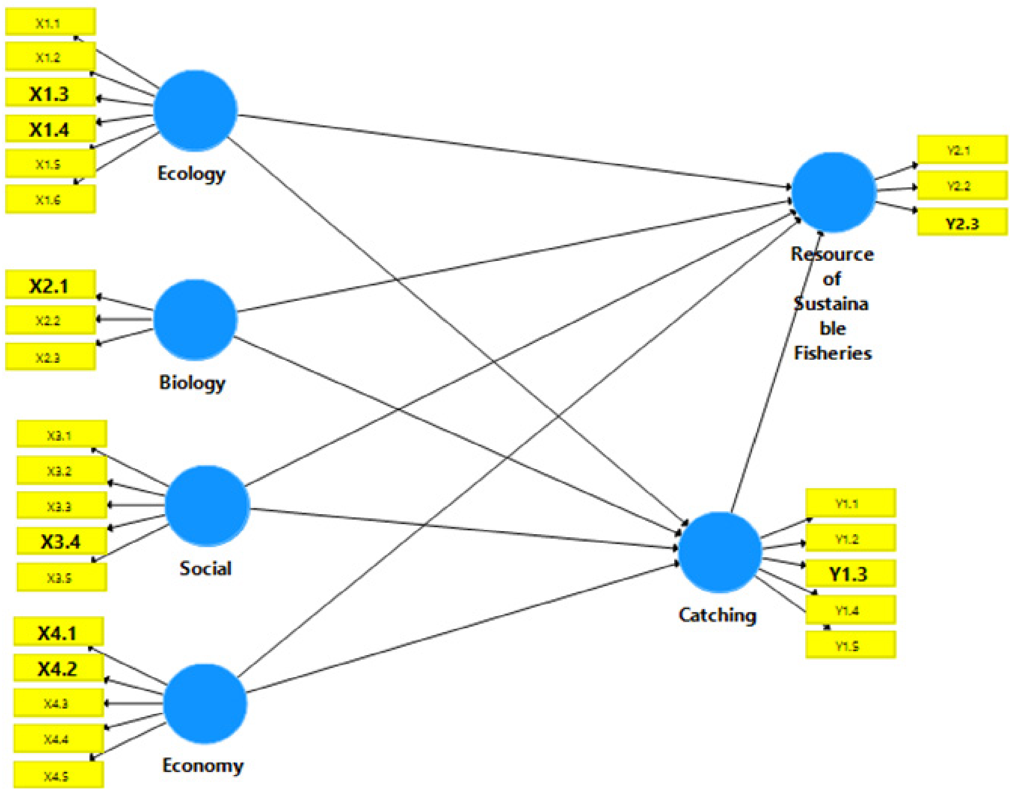

Figure 2. The path diagram model of the relationship between latent variables.

3.1.5 Structural model test (inner model)

Subsequently, the process of conducting structural testing, specifically focusing on the inner model, takes place once the measurement model, known as the outer model, has been tested and meets the necessary criteria. In order to assess the internal model, we analyzed the r-square value (which indicates the reli ability of the indicator) for the dependent latent variable Effect Size (f-square), as well as the significance of the coefficients for the structural path parameters.

3.1.6 Coefficient determination

The coefficient of determination is a quantitative measure that assesses the degree to which the independent variable may explain the dependent variable. As per Hair *et al.* (2019), an R-square value of 0.75 signifies a high ability of the endogenous variable to predict the model, whereas 0.50 indicates a moderate ability, and 0.25 suggests a low ability. The R-Square value, a statistical measure of how well the regression model fits the observed data, can be employed to assess the structural model's perfor

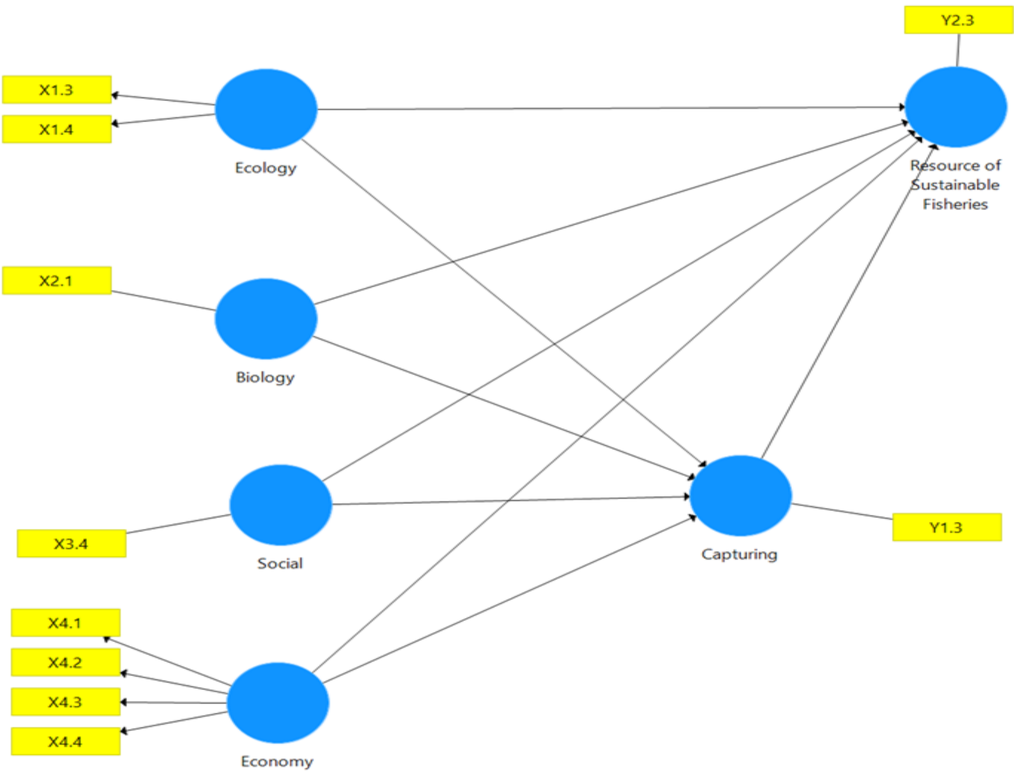

Figure 3. Path diagram model of the relationship between latent variables after validation.

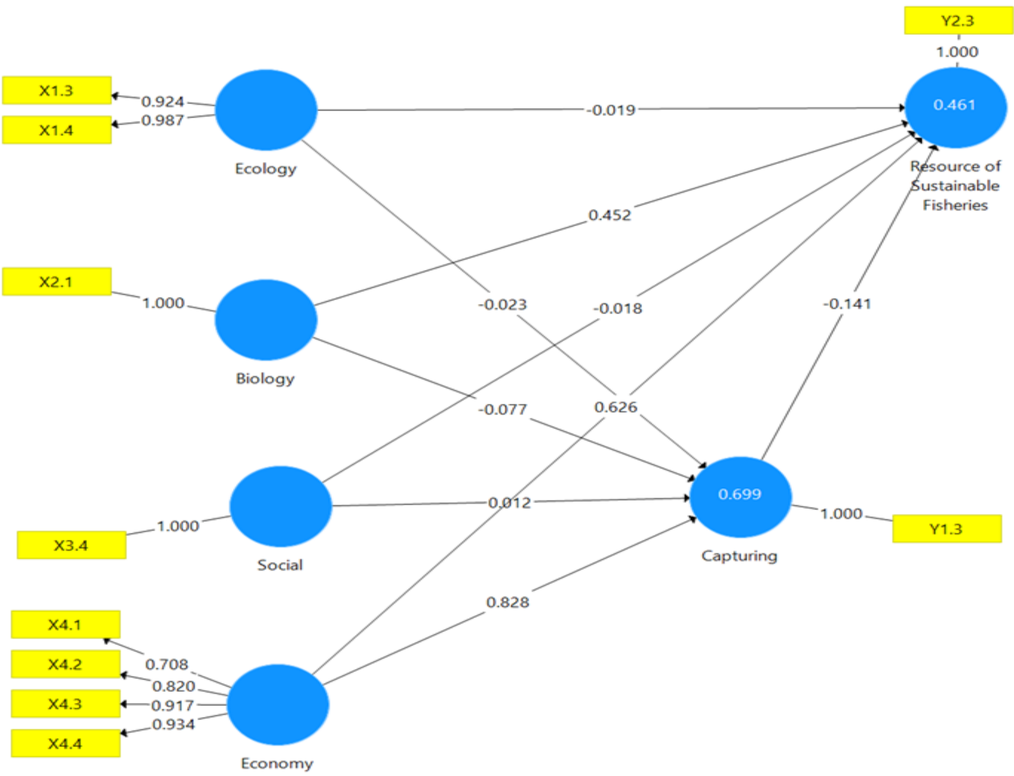

Figure 4. Outer model research on SmartPLS 3.

mance, as demonstrated in .fornell-Larcker criterion value (Table 5).

The dependent variable Capturing has a strong ability to forecast the model (0.699), while Sustainable Fisheries has a weak ability to predict the model (0.461), as indicated by value of R square (Table 6). The independent variables eco-biology and socio-economy have a 69.9% influence on the shellfish fishing enterprise, while the remaining variables are influenced by factors outside of this research. Sustainable fisheries exert a 46.1% influence on the dependent variable (capturing), whereas the other variables are affected by external factors beyond the scope of the research.

Table 2. Outer loadings value.

	Biology	Catching	Economy	Ecology	Social	Sustainable Fisheries
X1.3				0.924		
X1.4				0.987		
X2.1	1					
X3.4					1	
X4.1			0.708			
X4.2			0.82			
X4.3			0.917			
X4.4			0.934			
Y1.3		1				
Y2.3						1

Table 3. Cross-loading value.

	Biology	Capturing	Ecology	Economy	Sustainable	Social
X1.3	-0.047	-0.031	0.924	-0.048	-0.050	0.035
X1.4	-0.039	-0.105	0.987	-0.090	-0.085	0.059
X2.1	1,000	-0.115	-0.043	-0.048	0.438	0.047
X3.4	0.047	-0.120	0.053	-0.154	-0.077	1,000
X4.1	0.389	0.495	-0.103	0.708	0.467	-0.141
X4.2	-0.112	0.672	-0.055	0.820	0.438	-0.102
X4.3	-0.159	0.833	-0.080	0.917	0.375	-0.133
X4.4	-0.178	0.784	-0.041	0.934	0.413	-0.150
Y1.3	-0.115	1,000	-0.085	0.832	0.331	-0.120
Y2.3	0.438	0.331	-0.077	0.491	1,000	-0.077

3.1.7 Hypothesis testing (bootstrapping)

The model was subsequently analyzed with the SmartPLS 3 program, utilizing the bootstrapping facility, to acquire test values for the structural model (inner model) or a model that connects between constructs (latent variables) that were constructed. Figure 5 illustrates the outcomes of the structural model's bootstrapping (interior model).

The bootstrapping menu in SmartPLS facilitates hypothesis significance testing through the analysis of the Path Coefficients table, namely the t-statistics and ρ-values columns. To test this hypothesis, the significance criteria of a ρ-value less than 0.05 and a significance level of 5% are used. A Path Coefficient is considered significant if the t-statistic is greater than 1.96. The path coefficient is a quantitative measure that can be utilized to assess the magnitude of the influence of a connection. A route coefficient below 0.30 signifies a moderate level of effect, while a path coefficient between 0.30 and 0.60 suggests a strong level of influence. A path coefficient above 0.60 indicates a very strong level of influence on the treatment.

Overall, the ecological construct has a limited impact on the constructs of shellfish fishing and sustainable fisheries. This is evident from the t-values (t-ecology-capture=0.516 and t-ecology-sustainable fisheries=0.363), which are lower than the recommended values (t-value 1.96), as shown in Figure 5 of the structural model. The biological component significantly influences the structure of sustainable fisheries and bivalve fishing, as indicated by the t-values (t-biology-capture = 2.141 and t-biology-sustainable fisheries = 9.265), which above the recommended values (t-value = 1.96).

Table 4. Construct reliability and validity values.

Variable	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
Biology	1,000	1,000	1,000	1,000
Capturing	1,000	1,000	1,000	1,000
Ecology	0.919	1,478	0.955	0.914
Economy	0.867	0.886	0.911	0.721
Resource of Sustainable Fisheries	1,000	1,000	1,000	1,000
Social	1,000	1,000	1,000	1,000

Table 5. Fornell-Larcker criterion value.

Variable	Biology	Capturing	Ecology	Economy	Resource of Sustainable Fisheries	Social
Biology	1,000					
Capturing	-0.115	1,000				
Ecology	-0.043	-0.085	0.956			
Economy	-0.048	0.832	-0.080	0.849		
Resource of Sustainable Fisheries	0.438	0.331	-0.077	0.491	1,000	
Social	0.047	-0.120	0.053	-0.154	-0.077	1,000

Table 6. Value of R square.

	R Square	R Square Adjusted
Capturing	0.699	0.693
Sustainable Fisheries	0.461	0.449

The social construct of fisherman has a negligible influence on the construct of sustainable fisheries and bivalve fishing, as indicated by the t-values (t-stat-social-capturing = 0.365 and t-social-sustainable fisheries = 0.341) being lower than the required values (t-value: 1.96). The economic framework significantly influences the frameworks of shellfish fishing and sustainable fisheries due to the high t-values (t-economy-capture = 29.047 and t-economy-sustainable fisheries = 7,165), which exceed the required values (t-value 1.96). Nevertheless, the impact of the capture construct value on the sustainable fisheries construct is minimal, given that the t-value (1.546) falls below the suggested threshold (1.96) (Table 7). The path coefficient value of bootstrapping results (direct effect) displays the path coefficient values, which represent the extent of positive and negative influences between different constructs.

The route coefficient's output value can be utilized to assess the relevance of the influence exerted by each construct variable, encompassing ecological, biological, social, economic, and sustainable fishing, and fisheries. Evaluate the structural model by examining the parameter coefficient values and t-statistic values of this path coefficient, using the original sample data.

The initial sample exhibits a parameter coefficient of -0.077 for the capture construct and 0.452 for the sustainable fisheries construct in relation to the biological construct variable. This indicates that the catch construct variable has a negative impact, which is statistically significant because the t-statistic value is 2.142, exceeding the threshold of 1.96. Additionally, the sustainable fisheries construct variable has a positive impact, which is also statistically significant as the t-statistic value is 9.265, surpassing the threshold of 1.96.

The coefficient for the capturing-construct variable in the original sample was -0.141. This indicates that there was no substantial impact on the construct variable of sustainable fisheries, as evidenced by the t-statistic value of 1.548, which is below the critical value of 1.96.

of 1.96. The initial sample exhibits a parameter coefficient of 0.828 for the catch construct variable and 0.626 for the sustainable fisheries construct variable about the economic construct variable. This elucidates the reason behind the favorable impact on the con

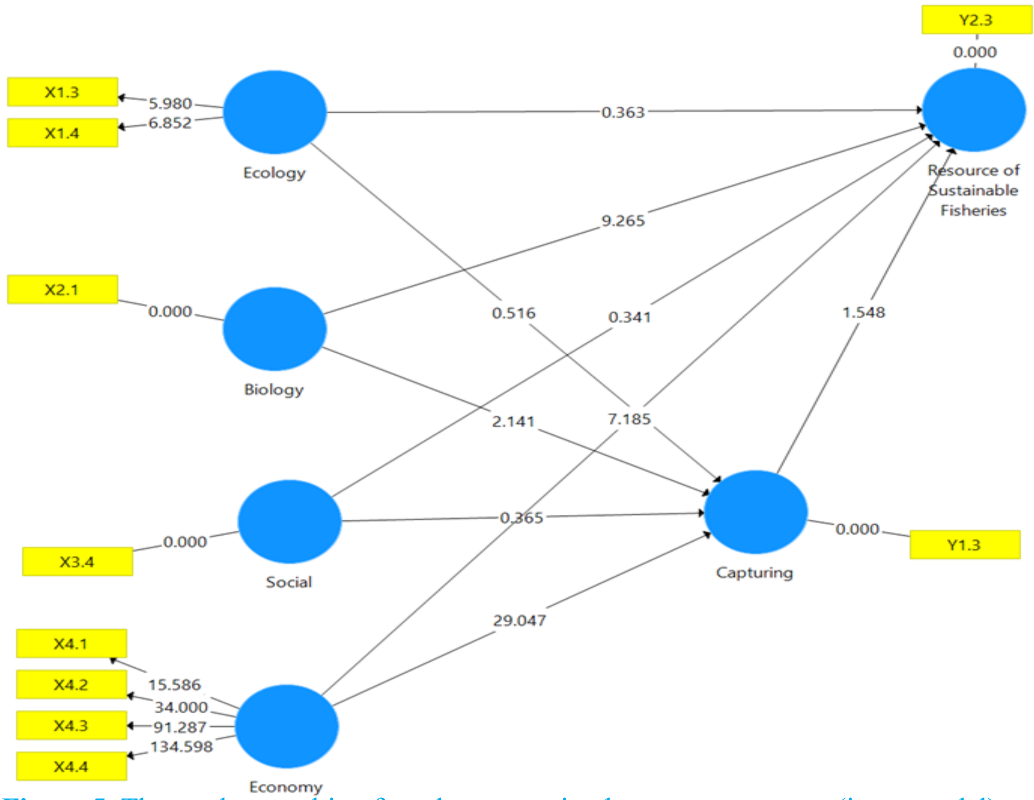

Figure 5. The t-value resulting from bootstrapping between constructs (inner model).

Table 7. Path coefficient value of bootstrapping results (direct effect).

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
Biology -> Capturing	-0.077	-0.075	0.036	2,141	0.033
Biology -> Resource of Sustainable Fisheries	0.452	0.455	0.049	9,265	0
Capturing -> Resource of Sustainable Fisheries	-0.141	-0.144	0.091	1,548	0.122
Ecology -> Capturing	-0.023	-0.023	0.045	0.516	0.606
Ecology -> Resource of Sustainable Fisheries	-0.019	-0.018	0.053	0.363	0.717
Economy -> Capturing	0.828	0.828	0.029	29,047	0
Economy -> Resource of Sustainable Fisheries	0.626	0.63	0.087	7,185	0
Social -> Capturing	0.012	0.01	0.034	0.365	0.715
Social -> Resource of Sustainable Fisheries	-0.018	-0.017	0.051	0.341	0.733

structed variable of sustainable fishing and fisheries, as well as the fact that the t-statistic value is 29.047 and 7.185, both of which exceed the threshold of 1.96.

The initial sample exhibits a parameter coefficient of 0.012 for the capture construct variable and -0.018 for the sustainable fisheries construct variable about the ecological construct variable. This indicates that the construct variable of sustainable fishing and fisheries experienced a negative impact, but the difference is not statistically significant. This is evident from the t-statistic value falling between the range of 0.365 to 0.341, which is less than the critical value

The initial sample exhibits a parameter coefficient of -0.030 for the catch construct variable and -0.009 for the sustainable fisheries construct variable to the social construct variable. This elucidates the reason behind the adverse impact on the construct variable of sustainable fishing and fisheries. However, the disparity is not substantial as indicated by the t-statistic values of 0.910 and 0.180, which are both below the threshold of 1.96.

Indirect effects refer to the impact of a construct or exogenous latent variable on endogenous latent variables through an intermediary variable that is itself endogenous. Based on the findings of the SmartPLS study, it can be concluded that none of the variables had a significant direct effect. This is indicated by the t-table value being less than 1.96, with specific sequential t-values of 1.326, 0.432, 1.522, and 0.292 (Table 8).

The fit model test employs many statistical indicators, such as the Standardized Root Mean Square Residual (SRMR), Normed Fit Index (NFI), and RMS_theta. To obtain an appropriate model, the indicator must satisfy certain criteria: SRMS should be less than 0.08, NFI should be greater than 0.90, and RMS_theta should be close to zero.

3.2 Discussions

The F-squared value results illustrate the relationship between biological variables and minor fish

Table 8. Path coefficient value of bootstrapping results (indirect effect).

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
Biology -> Capturing					
Biology -> Resource of Sustainable Fisheries	0.011	0.01	0.008	1,326	0.186
Capturing -> Resource of Sustainable Fisheries					
Ecology -> Capturing					
Ecology -> Resource of Sustainable Fisheries	0.003	0.004	0.008	0.432	0.666
Economy -> Capturing					
Economy -> Resource of Sustainable Fisheries	-0.117	-0.119	0.077	1,522	0.129
Social -> Capturing					
Social -> Resource of Sustainable Fisheries	-0.002	-0.001	0.006	0.292	0.771

3.1.8 Models for fitness

The study yielded the following results: the RMS Theta (Root Mean Square Theta) value was 0.309, the SRMR (Standardized Root Mean Square) value was 0.098, and the NFI (Normed Fit Index) value was 0.671. The RMS Theta value was less than 0.102, the SRMR value was less than 0.10 or 0.08, and the NFI value was greater than 0.9. The model created belongs to the Fit category, although the RMS Theta and NFI values do not conform to the requirement (Table 9).

ing variables, together with their influence on moder ately sustainable variables. The fishing variable exerts minimal influence on sustainability, but the economic variable significantly affects fishing and has a negligible impact on fisheries sustainability. Ecological variables have distinct effects compared to capture variables or sustainable variables. Sarstedt *et al.* (2021) classify the F-square value as follows: values below 0.02 can be ignored or signify no impact, values between 0.02 and 0.14 indicate a minor influence, values between 0.15 and 0.35 indicate a moderate effect, and values over 0.35 show an effect. Based on the R

Table 9. Fit models test.

	Saturated Model	Estimated Model
SRMR	0.08	0.08
d_ULS	0.35	0.35
d_G	0.261	0.261
Chi-Square	294,385	294,385
NFI	0.803	0.803

square analysis, the exogenous variable had a 69.4% influence on the catching variable and a 44.9% influence on the sustainable fisheries variable. According to the study conducted by Hair *et al.* (2019), a model with a R square value of 0.75 is classified as being in the strong category. A number of 0.50 would be categorized as moderate, but a value of 0.25 would be labeled as weak.

The built model is valuable since the Q Square value is more than 0.05, which indicates the accuracy of the exogenous elements in predicting the endogenous variables. The examination of the smartPLS calculations indicated that specific outer loading values fell below the 0.7 criterion. As a result, multiple observable variables were eliminated. Nevertheless, it is important to mention that certain sources deem exterior loading values exceeding 0.5 as permissible. According to Sarwono (2012), an outside loading value of 0.5 is considered acceptable for inclusion in models that are still in the process of being created. Nevertheless, models that have a value lower than 0.50 should be eliminated from the study. An indicator is deemed to possess strong validity if its outer loading value is above 0.70.

The catch of shellfish is significantly influenced by biological parameters, as indicated by a T-statistic test value of 2.141, which exceeds the critical value of 1.96. Furthermore, biological factors significantly contribute to the sustainable management of shellfish, with a numerical value of 9.265. In this context, the term "manifest variable" pertains to the specific timeframe during which the fishing season for shellfish in Sedati waters, Sidoarjo, takes place. This variable significantly influences the number of captures and also contributes to the application of sustainable shellfish management strategies. Rochana *et al.* (2019) discovered that the season and timing of fishing have a substantial influence on the number of catches.

The extended duration of the fishing season (X2.1) will directly affect the quantity of clams that are captured. The production per trip (Y1.2) is higher. Furthermore, the duration of the fishing season (X.2.1) will also influence the welfare of fishermen (Y2.3). Nevertheless, the practice of overfishing will inevitably lead to the excessive exploitation of shellfish resources. According to a study by Wati *et al.* (2014), overfishing has negative consequences for fishermen, including decreased catches, the need to travel further to find fishing grounds, resulting in greater expenses, and a decline in fishermen's revenue, notwithstanding cheap fish prices among them.

The capture factor for batik shellfish has a significant impact on sustainable management, as indicated by a t-value of 1.548. This implies that the total production per trip (Y1.2) does not have any influence on the well-being of shellfish fishermen (Y2.3). Production activities can influence the well-being of fishermen, as stated by Kusumayanti *et al.* (2018). Production affects the level of welfare experienced by fishermen. (Sastrawidjaya, 2002) asserts that the utilization of advanced technology and fishing equipment by fishermen leads to a proportional rise in productivity, resulting in higher production levels and subsequently boosting the income of the community.

The ecological parameters present in the batik shellfish habitat did not exert a substantial influence on both the capture of shellfish and the sustainable management of shellfish. This is supported by the T-statistic test values, which were less than 1.96, specifically 0.516 and 0.363. The ecological factors in this scenario are represented by two manifest variables: pH (X1.3) and temperature (X1.4). On the other hand, the fishing aspect is measured by the manifest variable of productivity per trip (Y1.2). The welfare factor of shellfish fishermen (Y2.3) is the main variable in sustainable shellfish management. The ecological factors of pH and water temperature do not have any impact on the overall annual or trip-based shellfish production. Furthermore, the welfare of shellfish fishermen remains unaffected by variations in pH and temperature. Wafi *et al.* (2019) propose that the welfare of fishermen can be assessed based on the number of catches they acquire from their fishing endeavors. The variation in catch levels can be attributed to the distinct fishing seasons that occur throughout the year.

The economic parameters that significantly influence the production per trip (Y1.2) in shellfish catching include gross income per year (X4.1), gross revenue per trip (X4.2), gross revenue per hour (X4.3), and gross revenue per worker (X4.4). Furthermore, the well-being of shellfish fishermen (Y2.3) is influenced by economic factors. This is evident from the T-statistic test results, where the t-values exceed 1.96, specifically 29.047 and 7.185.

Pradnyawati and Cipta (2021) discovered a direct and significant association between output levels and income. The quantity of products yielded by fishermen in each harvest will influence the revenue obtained by them. Laksamana and Fauziah (2021) believe that a positive association exists between the economic status of a town and the welfare of fishermen. Consequently, when the community's wealth rises, the welfare of fishermen also improves. The T-statistic test scores of <1.96, specifically 0.365 and 0.341, demonstrate that social features among shellfish fishermen exerted no substantial influence on shellfish harvesting or the sustainable management of shellfish. The manifest variable for social is shown by the number of organizations (X3.4), whereas the manifest variable for production per trip is represented by Y1.2. The welfare factor of shellfish fishermen (Y2.3) is the primary issue in sustainable shellfish management. The social factors in this instance relate to participation in organizations that do not influence the productivity of fishermen or the welfare of shellfish harvesters. Rahmah (2017) posits that the existence of the organization and the participation of fishermen are expected to positively impact the fishermen's income. Implementing fisheries management strategies that are grounded in ecological and biological principles is of utmost significance when it comes to effectively managing shellfish populations. Management employs models to assess the consequences of different rules on shellfish fishing, including catch quotas, size limitations, and temporary closures during specific seasons. The management aims are to optimize economic earnings, uphold biodiversity, guarantee food security, and sustainably conserve marine habitats. The effective governance of shellfish necessitates the active participation of key stakeholders, including fishermen, scientists, government agencies, and conservation organizations, in the decision-making process. (Aanesen *et al*., 2014) Emphasized the crucial significance of stakeholders in the management of capture fisheries. The objective of shellfish management is to enhance the social and economic benefits for fishermen, while simultaneously giving top priority to the ecological sustainability of shellfish. According to a study conducted by Suharno *et al*. (2020) and Agustini (2015), environmental preservation and the inclusion of human factors are interconnected, as humans are both social and economic beings.

By incorporating ecological-biological shellfish and socio-economic fishermen modeling into fisheries management, the aim is to foster the development of more sustainable practices that safeguard shellfish populations, preserve marine ecosystems, and promote the long-term viability of the fishing sector. According to Failler *et al*. (2022), the use of integrated Socio-Economic-Ecological Modelling for Fisheries can enable the fishing sector to adopt suitable policy measures in order to address the issue of excessive resource extraction and maintain a sustainable economic equilibrium.

The analysis of predictive power for sustainable fisheries management reveals varying strengths of relationships between ecological and social factors. The R^2 values indicate a strong predictive ability for shellfish capture (0.699), while the model's fit for sustainable fisheries management is moderate (0.461), suggesting that additional variables likely influence sustainability beyond those currently analyzed. Weaker relationships among certain factors imply that they may not be primary drivers of successful fisheries management, highlighting the need for a focused approach to identify key influences. The findings advocate for incorporating a broader array of ecological and social factors into management strategies, such as economic incentives, community engagement, regulatory frameworks, and environmental conditions. Future research should aim to enhance the model's predictive power by integrating these additional factors, potentially through qualitative studies for local context or quantitative analyses to test new variables. A holistic approach that considers the interplay of various factors may yield better insights and strategies, leading to more effective policies and practices that address the complexities of marine ecosystems and the communities reliant. Overall, while the current model offers valuable insights, further exploration and refinement are essential for improving its predictive capabilities in sustainable fisheries management.

Effective governance frameworks are essential for sustainable aquaculture practices, as exemplified by the adoption of integrated multi-trophic aquaculture (IMTA) in Europe, which necessitates flexible and supportive regulatory environments (Alexander *et al*., 2015). However, current frameworks are often complex and may require substantial reform to facilitate commercial expansion. Maximizing inclusiveness in governance, particularly by involving affected stakeholders, is crucial for ensuring that decision-making processes are accepted and effective, which is vital for sustainability. Different management strategies, such as those implemented in the Dutch Wadden Sea, demonstrate that informed decision-making based on ecological modeling and multi-criteria analysis can significantly enhance the sustainability of shellfish reefs by clarifying the impacts of various management choices on ecosystem services (Rindorf *et al*., 2017). The UN Sustainable Development Goals underscore the importance of good governance for sustainable resource management, advocating for a governance framework that incorporates quality criteria and indicators to assess and improve governance practices, which is essential for fisheries sustainability. Furthermore, effective governance must tackle challenges such as overfishing, habitat destruction, and climate change, with recommended measures including ecosystem-based fisheries management, gear restrictions, and improved compliance to bridge the gap between scientific knowledge and governance.

4. Conclusion

Based on the model analysis, three items showed no significant relationships between capture factors and sustainable fisheries management, ecological factors and shellfish capture and sustainable fisheries and sustainable fisheries management, social factors and the capture of shellfish. Biological factors and shellfish catchment and management economic factors influence the shellfish capture showed significant influence on the fisheries management. The development of this model can serve as a benchmark for shellfish fishing activity in this coastal water. Overfishing or other anthropogenic activities in this area can be monitored using this model. The purpose is to control or monitor the stock and the inventory of the shellfish fisheries to preserve them for further use. Based on the results of hypothesis testing via Bootstrapping in the SmartPLS 3 program, it can be concluded that the biological factors of shellfish have a significant effect on shellfish catching, one of the factors being the size of the shellfish caught. Apart from that, biological factors also have a significant influence on the sustainable management of shellfish, because if fishing for large-sized is carried out too massively, the availability of shellfish resources will be disrupted and this will result in fishermen's income decreasing. Apart from that, catching shellfish that are too small will also have an impact on disrupting the ecosystem in the waters. Economic factors have a significant effect on shellfish caching because the more shellfish caught, the income of shellfish fishermen will directly increase, economic factors also have a significant influence on the sustainable management of shellfish. The greater the income of fishermen, the greater the availability of shellfish stocks will be because the fishing effort carried out by fishermen will be massive.

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Authors' Contributions

Kustiawan Tri Pursetyo as researcher and article author. Mohd Hanafi Idris, Alfian Zein, Endang Dewi Masithah as supervisors in research and article writing.

Conflict of Interest

There is no conflict of interest in this article. The article originated from research data and the article has been approved by all authors for publication together.

Declaration of Artificial Intelligence (AI)

AI Declaration Statement

The authors affirm that no artificial intelligence (AI) tools, services, or technologies were employed in the creation, editing, or refinement of this manuscript. All content presented is the result of the independent intellectual efforts of the author(s), ensuring originality and integrity.

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