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Modelling Adaptation to Climate Change among Small-Scale Fishermen in Bengkulu Province in Indonesia

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Received: 06-16-2025 **Revised:** 08-28-2025 **Accepted:** 09-18-2025

Citation: Mulyasari, G., Cahyadinata, I., Irham, & Hadi, A. I. (2025). Modelling adaptation to climate change among small-scale fishermen in Bengkulu Province in Indonesia. *Chall. Sustain.*, *13*(4), 508–524. https://doi.org/10.56578/cis130403.

Abstract: Climate change poses severe challenges to small-scale fisheries, which require critical adaptation strategies. This study developed a model of climate change adaptation among small-scale fishermen in Bengkulu Province, Indonesia, using a framework that links poverty, livelihood vulnerability, and adaptive capacity. This study contributes novel empirical evidence on how these factors interact to shape adaptive behavior in small-scale fisheries within a developing country context. Data was collected from a survey of 700 fishing households selected by quota sampling. The direct and indirect relationships among socioeconomic variables and adaptation strategies were examined using path analysis in Statistical Package for the Social Sciences (SPSS) and Analysis of Moment Structures (AMOS). The findings revealed that poverty had a significantly adverse effect on the adaptive capacity of fishermen, limiting their capability to respond effectively to climate stressors. Consequently, a majority of fishermen relied on low-cost and easily implemented strategies, such as adjusting fishing times and shifting fishing grounds. Fishing experience, vessel capacity, fishing distance, and the type of fishing gear, in contrast, showed significantly positive effects on adaptation. These results underscore that economic constraints weaken adaptive capacity, while technical assets and practical knowledge enhance resilience. The policy implications highlighted the imperative to strengthen fishermen's institutions, update fleets, establish cooperatives, diversify fishing gear, and provide accessible digital climate information services. Such governmental interventions are crucial for enhancing adaptive capacity, supporting the sustainable management of fisheries, and improving the economic resilience of coastal communities.

Keywords: Adaptation; Climate change; Livelihood vulnerability; Poverty; Small-scale fishermen

1. Introduction

Global climate change, primarily driven by human activities, has increased the Earth's surface temperature by approximately 0.85℃ over the last century. Projections indicated that by the end of the twenty-first century, this increase would have reached at least 1.5℃ (IPCC, 2014). The trends of recent warming have exacerbated poverty and inequality; these issues are expected to worsen, particularly in vulnerable regions, as global temperatures continue to rise beyond 1.5℃ (IPCC, 2018; Kaua et al., 2021). Coastal areas are particularly susceptible to climate change due to the combined effects of land and sea factors. Climate change has four primary impacts on coastal regions: (1) rising sea levels; (2) shifts in storm patterns and rainfall; (3) increasing temperatures of coastal water; and (4) ocean acidification (EPA, 2013). In recent years, fishermen have observed significant disruptions in seasonal patterns, closely aligning with the broader impact of global warming. Uneven seasonal wind patterns have increased the difficulties for fishermen in determining safe and effective fishing times in the sea (Siregar & Civil Society Forum for Climate Justice, 2011). Many fishermen misjudge seasonal wind patterns, posing risks to their safety and fish catches. This challenge is particularly pronounced for fishermen operating in waters adjacent to the open ocean, such as those along the western coast of Sumatra, southern Java, Bali, West Nusa Tenggara

(NTB), East Nusa Tenggara (NTT), and northern Papua. Miscalculations can lead to hazardous encounters with high waves and strong winds, sometimes resulting in the sinking of fishing vessels.

Climate change further intensifies the vulnerability of coastal communities, which are already at risk due to erosion and human activities that degrade coastal ecosystems. Increased climate variability disrupts fishing operations, as harsher sea conditions reduce fishing opportunities and catch volumes. This, in turn, negatively impacts the incomes of households, particularly those who rely solely on the fisheries sector for their livelihood. The economic challenges faced by fishermen due to declining fish stocks and unstable marine ecosystems underscore the urgent need for adaptation strategies.

As the frequency of climate-related disasters has increased and climate projections have gained credibility, adaptation has become a global priority (IPCC, 2014). The primary objectives of climate adaptation include reducing vulnerability, strengthening resilience, and fostering climate-resilient fisheries. This involves modifying fishing practices, resource management, and operational strategies to align with changing climatic conditions (Shaffril et al., 2017). The crucial component of adaptation, adaptive capacity, refers to a system's ability to mobilize resources, recover from stressors, and continue functioning despite environmental shocks (Engle, 2011). Strengthening adaptive capacity helps mitigate socioeconomic and biophysical vulnerabilities linked to climate change.

Adaptation to climate change can be spontaneous or planned, depending on the urgency of environmental changes and the available resources (Murdiyarso, 2003). Effective adaptation strategies involve reducing vulnerability, enhancing resilience, and increasing adaptation capacity to determine the success of these actions (Smit & Wandel, 2006). From a sociocultural perspective, adaptation is also a component of cultural evolution, representing the adjustment of individuals and communities to environmental and social changes over time (Helmi & Satria, 2012). Responsive behaviors, shaped by past experiences, enable individuals to develop coping mechanisms and strategies to navigate changing conditions (Bennett, 2005; Ogunbode et al., 2024). Various factors affect the adaptation to climate change in the fisheries sector. Key determinants include poverty (Yesuph et al., 2023), access to technology (Meena et al., 2019), resource availability (Jha & Amarnath, 2011), knowledge, infrastructure, financial markets, economic conditions, and overall wealth (Panda, 2016). Since adaptation requires logical, practical, and cost-effective solutions, individual fishermen play a crucial role in determining how to respond to fluctuating weather patterns and changing marine conditions.

Studies on climate change and adaptation have been widely carried out (Ding et al., 2011; Fahad & Wang, 2018; Handayani et al., 2019; Jamshidi et al., 2019; Kim et al., 2024), and only a few concerns poverty and livelihood vulnerability as variables in adaptation to climate change (Baptiste & Kinlocke, 2016; Burnham & Ma, 2015; Koehn et al., 2022; Oo et al., 2018). Most studies on adaptation to climate change were partially related to policy and regional vulnerability. Rarely does climate change adaptation analysis fully incorporate an understanding of climate change, poverty, and livelihood vulnerability as determining factors (Andrista et al., 2025; Herreros-Cantis et al., 2025; Mensah et al., 2025; Zeray, 2025). This study reveals not only the issue of climate change but also its effects on poverty, livelihood vulnerability, and adaptation as perceived by fishermen. Research related to the impact of climate change on fishermen in Indonesia was minimal; those in existence are mainly about adaptation strategies and primarily on the agricultural sector (Nurhidayah & Mcllgorm, 2019; Susilowardhani, 2014; Yamamoto & Esteban, 2014; Zikra et al., 2015), particularly on Java Island, the center of economic growth in Indonesia.

Bengkulu Province, situated on the western coast of Indonesia, is particularly vulnerable to the impacts of climate change. The region, with a coastline of approximately 525 km along the Indian Ocean, features relatively narrow coastal plains highly susceptible to climate-related disasters, including floods, landslides, extreme weather events, tornadoes, and droughts. Notably, North Bengkulu Regency, located on Bangkai Island and Satu Island, is gradually sinking due to rising sea levels, while Enggano Island is experiencing a size reduction (Wongke, 2011). Additionally, coastal erosion poses a severe threat to local communities. According to Nurcholis Sastro, Disaster Coordinator at the Women's Crisis Center (WCC) Cahaya Perempuan in Bengkulu, at least 20 villages along the Bengkulu coast are expected to be submerged by 2040 due to rapid coastal erosion (Kupasbengkulu, 2013). Most fishermen reported growing concerns about unpredictable weather patterns, which have become increasingly chaotic and challenging to forecast. Traditionally, fishermen have relied on inherited knowledge and generational experience to determine the best times for fishing. However, the shifting climate has rendered these time-tested references unreliable, forcing many fishermen to fish under dangerous and uncertain conditions.

Given the heightened vulnerability of small-scale fishermen, this study developed a model to address climate change adaptation strategies. The research considered multiple factors, including poverty, livelihood vulnerability, vessel size, fishing distance, fishermen's awareness of the impact of climate change, and other relevant socioeconomic and environmental variables. In this study, understanding these interconnections could provide valuable insights into how small-scale fishermen could build resilience against climate change and sustain their livelihoods in the face of increasing challenges.

2. Framework of Research

Fishermen constitute one of the most vulnerable groups susceptible to the impact of climate change, particularly in developing countries such as Indonesia, where around 90% of the 16.2 million fishermen live below the poverty line (Acheson, 1981; Emerson, 1980). Poverty among fishermen is multidimensional, reflected not only by their low income but also by their restricted access to education, health services, technology, and institutional support (Nurkse, 1953; Nurwati, 2008). These limitations reduce their ability to anticipate, respond to, and recover from climate-related shocks, thus creating a strong link between poverty and livelihood vulnerability (Cutter et al., 2003).

Livelihood vulnerability refers to the degree of exposure, sensitivity, and adaptive capacity of fishing households to external and internal stressors (Chen & Lopez-Carr, 2015). In coastal communities, climate change increases vulnerability by reducing fish stocks, damaging ecosystems, and amplifying risks from extreme weather (IPCC, 2014; Shaffril et al., 2017). Vulnerability is further exacerbated when socioeconomic conditions prevent fishermen from accessing adaptive strategies, such as diversifying livelihoods and upgrading fishing gear. Thus, poverty and vulnerability are interrelated factors jointly undermining adaptive capacity (Yesuph et al., 2023).

Adaptation is recognized as the primary strategy for minimizing risks and enhancing resilience in the fisheries sector (Smit & Wandel, 2006). However, empirical studies often remained descriptive, failing to integrate causal relationships among poverty, livelihood vulnerability, and adaptive responses. To address this gap, the present study incorporated the Multidimensional Poverty Index (MPI) and the Livelihood Vulnerability Index (LVI) into a structural model to explain fishermen's adaptation strategies. Socioeconomic characteristics, including age, education, fishing experience, vessel capacity, fishing distance, and fishing gear, were identified as critical determinants (Abid et al., 2019). Moreover, fishermen's awareness of climate change mediated the relationship between vulnerability and adaptation, as higher awareness fostered proactive adjustments (Piggott-McKellar et al., 2019).

Institutional support also plays a moderating role. Strong fishing cooperatives, access to climate information, and government assistance could strengthen adaptive capacity by enhancing resource availability and collective action (Gupta et al., 2010; Heydari et al., 2021; Olayide & Alabi, 2018). Without institutional reinforcement, adaptation, such as adjusting fishing times and changing fishing grounds, remains low-cost and reactive, hence insufficiently addressing long-term risks (Helmi & Satria, 2012).

The research framework posits that poverty and livelihood vulnerability negatively affect adaptation strategies, while socioeconomic characteristics and awareness positively influence adaptation (Figure 1). The novelty of this study lies in empirically demonstrating that multidimensional poverty and livelihood vulnerability jointly shaped adaptive behaviors among small-scale fishermen in Bengkulu Province. Evidence was provided to support policy interventions that combine poverty alleviation, climate information services, and institutional strengthening.

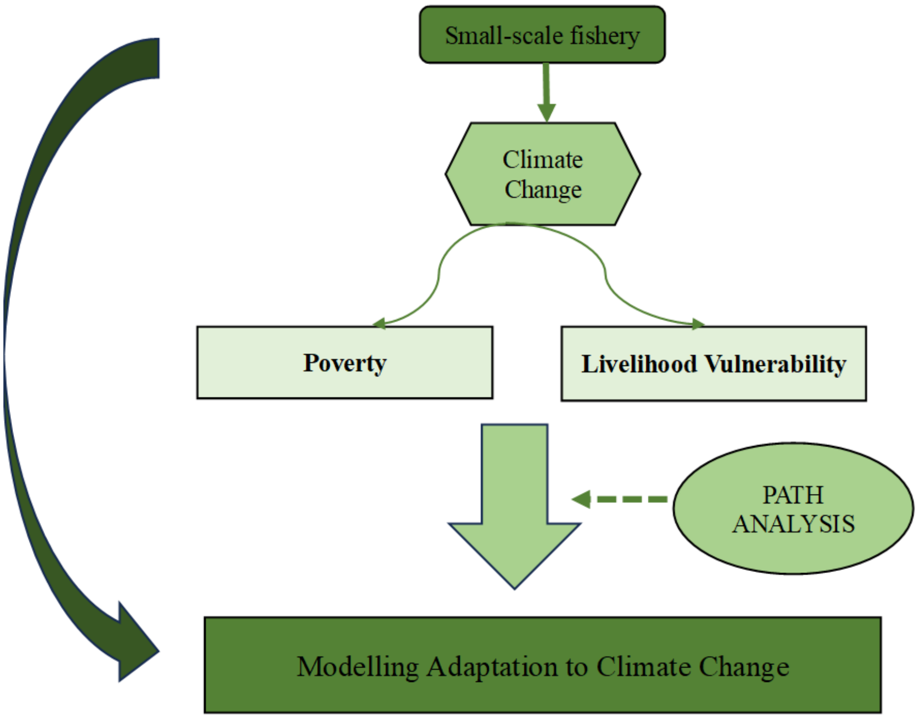


Figure 1. Framework of research on the interrelationship among poverty, livelihood vulnerability, and modelling adaptation to climate change

3. Methodology

3.1 Description of the Study Area

Bengkulu City, Central Bengkulu Regency, North Bengkulu Regency, Mukomuko Regency, South Bengkulu Regency, and Kaur Regency were coastal regions covered in this study, as shown in Figure 2. Bengkulu Province is situated to the west of the Bukit Barisan highlands. Its total area is 19,919.33 square kilometers or 1,991,933 hectares, and its boundary with West Sumatra Province is around 567 km away (Mulyasari et al., 2023).

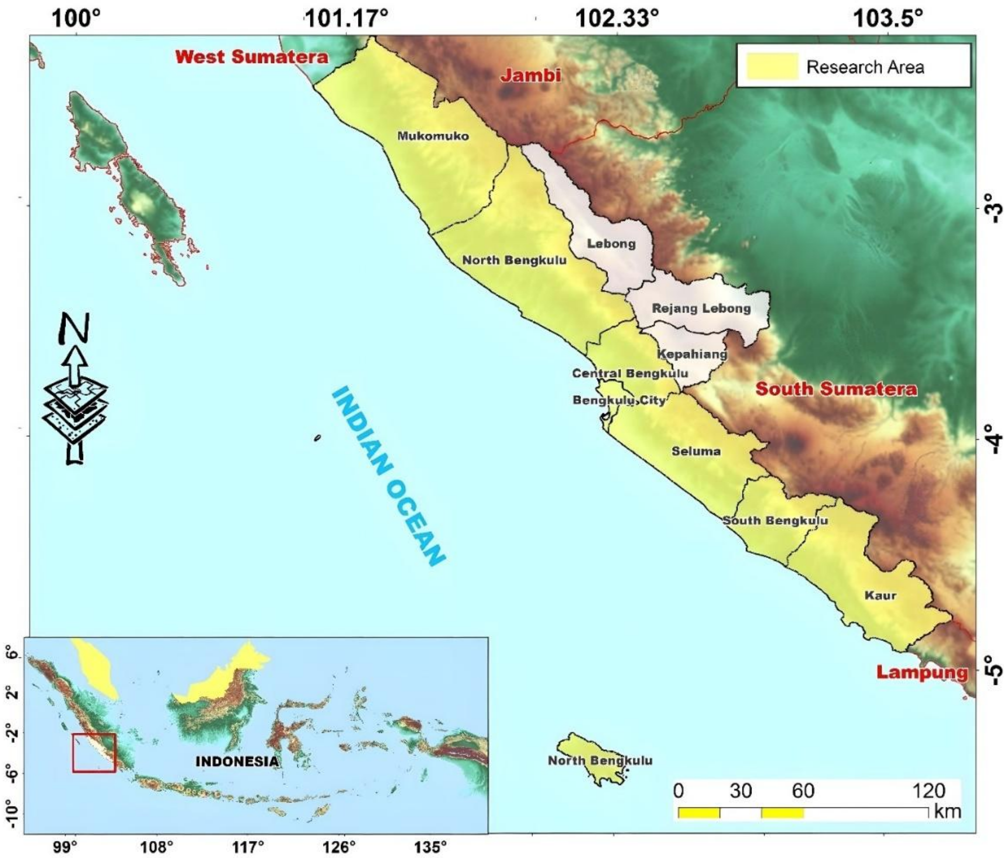


Figure 2. Locations of research processed by authors in 2024

Bengkulu Province has a coastline that stretches approximately 525 km along the Indian Ocean. It is located between latitudes 2°16′ and 3°31′ south and longitudes 101°01′ and 103°41′ east. While the western portion comprises relatively narrow, low-lying lands stretching north to south and dotted with undulating landscapes, the eastern portion features steep terrain and rich highlands. The seas of Bengkulu Province act as a meeting point of four major ocean currents, forming an essential center of climate variability. This interaction produces rain clouds through evaporation processes, which affect seasonal patterns and the world climate (Mulyasari et al., 2023). Due to its vulnerability to extreme climate, Bengkulu Province, located on the western coast of Sumatra Island, was specifically chosen for this study.

3.2 Sampling and Collection of Data

The data for this study were collected by a questionnaire survey comprising 700 small-scale fishing households in the coastal districts of Bengkulu Province. Figure 3 illustrates the sampling procedure, in which quota sampling was employed to select the respondents. This study examined small-scale fisheries, such as artisanal or traditional fisheries, characterized by fishing households that use relatively small vessels (≤ 10 GT), undertake short fishing trips typically lasting one day, and possess limited resources. The questionnaire consisted of four major components: the first part involved asking respondents about their age, education, level of experience with fishing, size of home, income, and other employment details. The second part examined features of small-scale fisheries, including boat power, number of fishing days, length of journey, fishing distance, catch capacity, membership in fishing associations, availability of loans, and access to climate data. The third part of the questionnaire focuses on multidimensional poverty and livelihood vulnerability, including exposure, sensitivity, and adaptive capacity based on 14 indicators of livelihood vulnerability as defined by Chen & Lopez-Carr (2015). The last part of the questionnaire is the adaptation of small-scale fishermen to climate change.

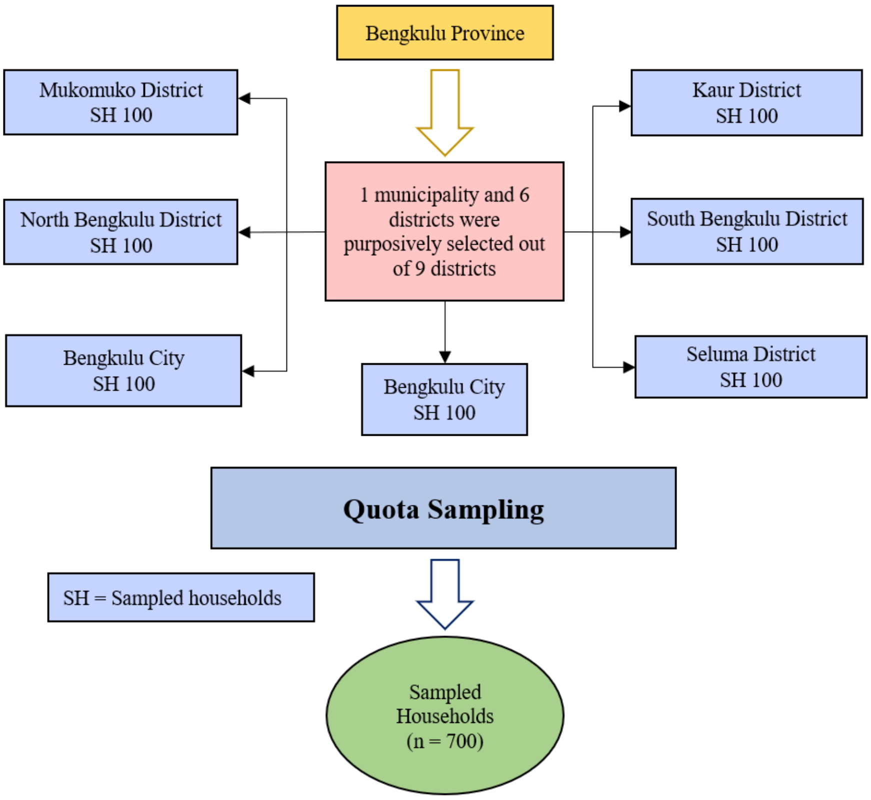


Figure 3. Schematic presentation of the sampling procedure

3.3 Analysis of Data

Path analysis was employed to create models that examined the effects of poverty, fishermen's awareness of the impact of climate change, and livelihood vulnerability on climate change adaptation. This technique is a multivariate method used to analyze the nature and causal relationships, both direct and indirect or mediated, among several variables. Generally, there are two methods for analyzing route models: (a) estimation using a model selection tool such as Analysis of Moment Structures (AMOS); and (b) multiple regression analysis. The multiple regression strategy was carried out using Statistical Package for the Social Sciences (SPSS), which estimates path coefficients using the ordinary least squares method. On the other hand, AMOS often computes path coefficients using maximum likelihood estimation, which helps determine parameter values that maximize the likelihood of the model being correctly specified. In addition to these benefits, AMOS evaluates the indirect and total effects of predictor variables, model fit, and the accuracy with which the model represents the data (Etemadi & Karami, 2016; Meyers et al., 2006).

Model estimation with the AMOS program is available, using the default maximum likelihood model. Model estimation was conducted using the AMOS program with the maximum likelihood method. To assess the suitability of the model, several goodness-of-fit (GOF) indices were employed. First, the chi-square statistic was used to determine whether the proposed model differed significantly from the observed data. Since chi-square is sensitive to large sample sizes, additional fit indices were used for a more reliable evaluation.

The Root Mean Square Error of Approximation (RMSEA) was calculated to assess the degree of approximation in the population, with values below 0.08 indicating an acceptable fit. The Goodness of Fit Index (GFI) and Adjusted Goodness of Fit Index (AGFI) were then used to evaluate the proportion of variance explained by the model, with values above 0.90 considered satisfactory. To account for model parsimony, the chi-square value was divided by the degrees of freedom (CMIN/DF), with a ratio ≤ 2.00 reflecting a good fit.

Furthermore, the Tucker–Lewis Index (TLI) and the Non-Normed Fit Index (NNFI) were employed to compare the specified model against a null model, where values above 0.90 indicated adequate fit. Together, these indices provided a comprehensive assessment of the overall model suitability, ensuring that the structural relationships tested were well supported by the data (Dachlan, 2014; Ferdinand, 2006).

4. Characteristics of Small-Scale Fishery

4.1 Socioeconomic Characteristics

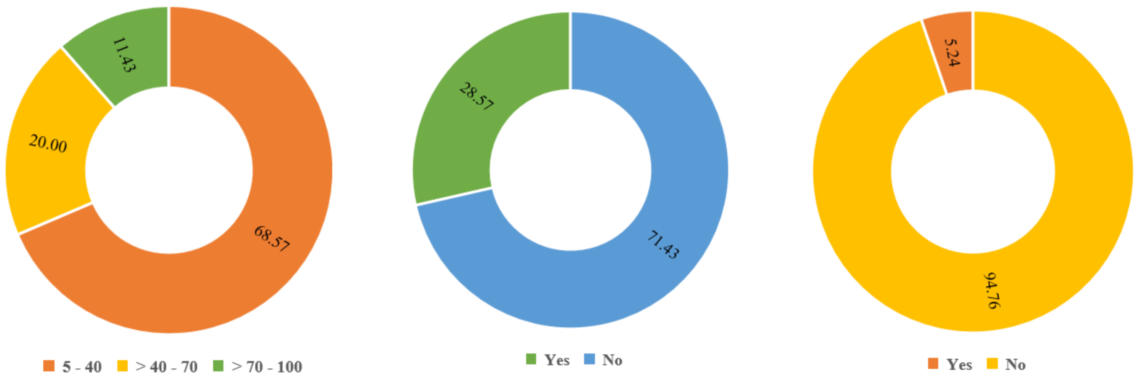
Table 1 illustrates the socioeconomic characteristics of the respondents and their households, including age, formal education, household size, fishing experience, fishing income, and side jobs.

Table 1. Characteristics of small-scale fishermen

Characteristics	Categories	Frequencies	Proportion (%)
Age (years)	17–35	230	32.86
	36–54	357	50.95
	55–74	113	16.19
Formal education	None	44	6.19
	Elementary school	460	65.71
	Junior high school	113	16.19
	High school	60	8.57
	University	23	3.33
Household size (person)	0–2	234	33.33
	3–5	443	63.33
	6–7	23	3.33
Fishing experience (years)	4–19	283	40.48
	20–34	294	41.90
	35–50	123	17.62
Fishing income ($/month)	31–340	553	79.05
	341–650	100	14.29
	651–930	47	6.67
Side job	Yes	153	21.90
	No	547	78.10

4.2 Characteristics of Small-Scale Fishermen

The characteristics of the respondents and their households, including ship weight, fishing time, fishing distance, fishing gear, use of a crewed ship, ship ownership, catch capacity, group membership, and access to climate information, were collected and presented in Figure 4.



(g) (h) (i)

Figure 4. Characteristics of small-scale fishermen: (a) Ship weight (gross tonnage); (b) Fishing time (hours); (c) Fishing distance (miles); (d) Fishing gear; (e) Use of crew ships; (f) Ship ownership; (g) Catch capacity (kg/trip); (h) Group membership; and (i) Access to climate information

5. Results of Analysis

5.1 Multidimensional Poverty of Small-Scale Fishermen

Poverty is a complex, multidimensional issue that encompasses various aspects of life and is a challenging problem affecting nearly every country worldwide, including Indonesia. Measurement of poverty, with a multidimensional perspective, uses non-monetary approaches to assess deprivation. Poverty extends beyond insufficient income or consumption levels, which are commonly measured against welfare standards, such as minimum calorie requirements or the poverty line. It reflects limited access to essential economic, social, cultural, and political resources, thereby hindering individuals from fully participating in society.

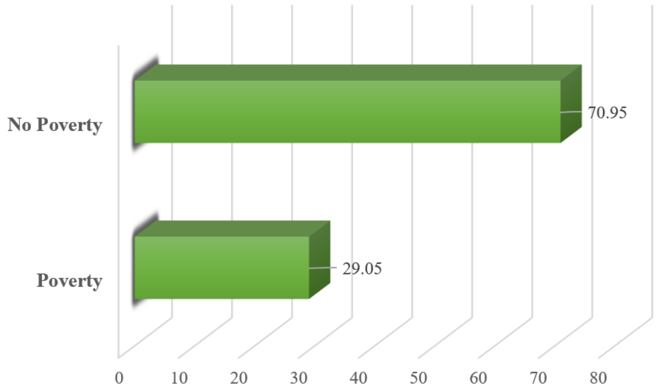
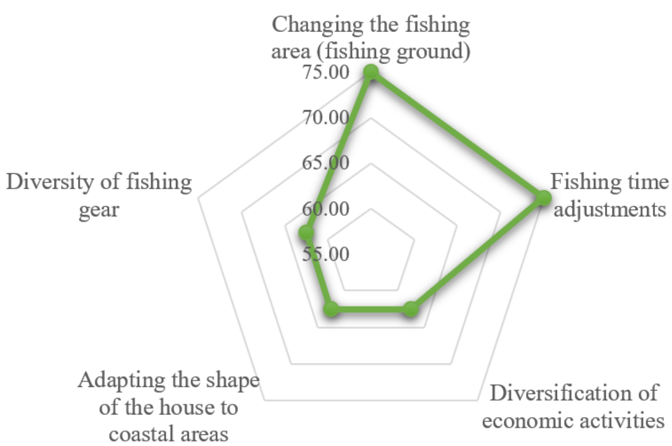
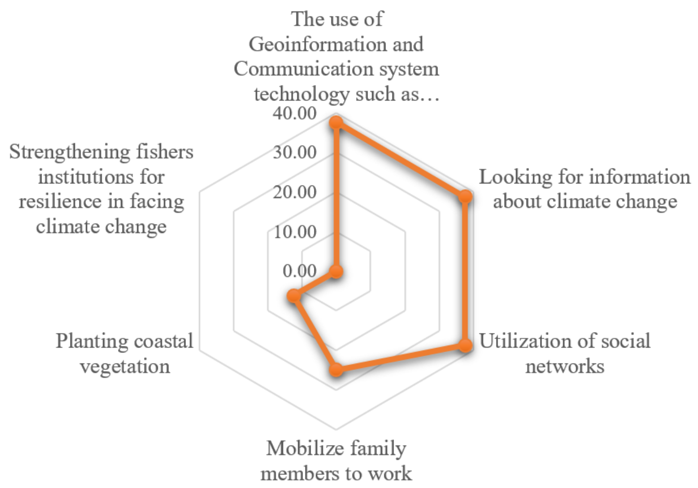


Figure 5. Percentages of poverty among small-scale fishermen in the coastal area of Bengkulu



(a)



(b)

Figure 6. Climate change adaptation (a) most frequently, and (b) rarely by poor fishermen

Moreover, poverty affects access to fundamental needs, including healthcare, education, clean water, and sanitation. As shown in Figure 5, the average poverty rate among fishers in the Bengkulu coastal area is 29.05%, exposing the problem of poverty in this vulnerable community.

Poor fishermen on the Bengkulu Coast employ low-cost climate change adaptation strategies that require minimal skills and resources. The typical strategy consists of: (1) adjusting fishing times to align with shifting seasonal patterns; and (2) modifying fishing areas or fishing grounds to follow fish migration patterns caused by varying ocean conditions in Figures 6a and 6b.

5.2 Livelihood Vulnerability of Small-Scale Fishermen

The vulnerability approach analyzes risks within a community and ecosystem, focusing on their exposure and ability to withstand external and internal disturbances. Figure 7 shows that most fishers (68.89%) are highly susceptible to the impacts of climate change, while only 31.11% fall into the non-vulnerable category.

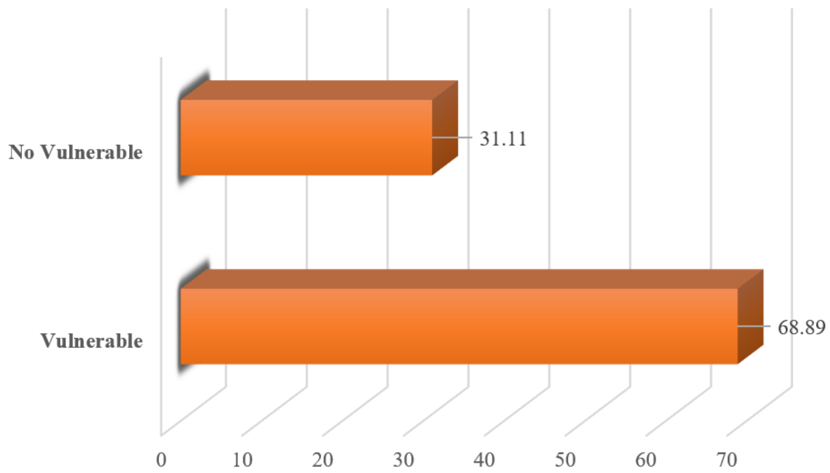


Figure 7. Livelihood vulnerability of small-scale fishermen

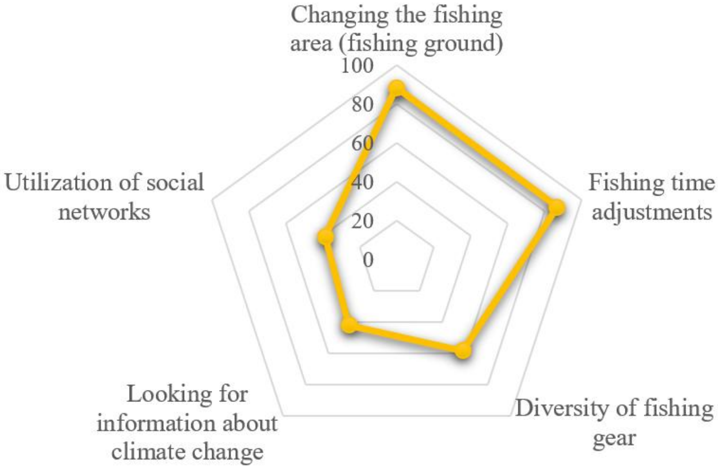
In particular, climate change has affected small-scale fishers through declining fish availability, unpredictable weather patterns, increased storm frequency, and higher operational costs. To cope with these impacts, fishers tend to rely on short-term strategies such as adjusting fishing grounds and times, reducing fishing trips during extreme weather, and utilizing basic ecosystem knowledge (e.g., tidal and seasonal patterns). However, their adaptive capacity remains limited due to financial constraints, inadequate access to technology, and weak institutional support, which further exacerbates livelihood vulnerability.

In the coastal areas of Bengkulu, fishers have experienced a significant decline in catches due to the loss of fishing grounds caused by climate change, as shown in Table 2.

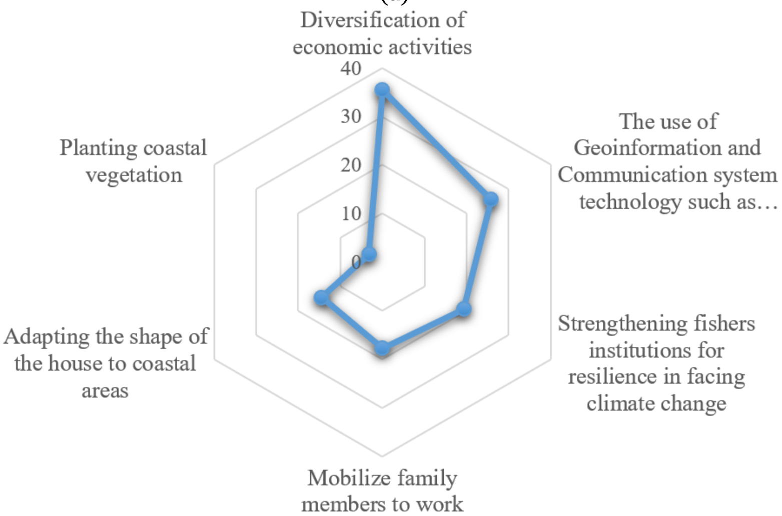
Table 2. Livelihood vulnerability index

Dimensions	Indicators	Mean	Status of Vulnerability*
Exposure	Decrease in catch	0.267	Low
Sensitivity	Fishery income	0.899	Very high
	Number of trips	0.574	Moderate
	Fishing income for operational costs	0.202	Low
	Fishermen who do not share the organization	0.350	Low
Adaptive Capacity	A poor fishing family	0.179	Very low
	Income as a fisherman	0.297	Low
	Number of active fishermen	**1.000**	**Very high**
	Average catch price	0.370	Low
	Fishing experience	0.481	Moderate
	Age of the fisherman	0.460	Moderate
	Non-fishery income	0.097	Very low
	Boat power	0.409	Moderate
	Catch capacity	0.279	Low

Note: *Status of Vulnerability: 0.0–0.2 (very low vulnerability); > 0.2–0.4 (low vulnerability); > 0.4–0.6 (moderate vulnerability); > 0.6–0.8 (high vulnerability); > 0.8–1.0 (very high vulnerability)



(a)



(b)

Figure 8. Adaptation strategies adopted by vulnerable fishermen (a) most frequently, and (b) rarely

To align with their economic and financial capabilities, small-scale fishermen in the Bengkulu coastal area adopt a range of climate change adaptation strategies. As shown in Figure 8a, the most common strategies include adjusting fishing times (around 75%), shifting fishing grounds (above 80%), and diversifying fishing gear. These strategies are widely practiced because they are low-cost, rely on existing local knowledge, and can be implemented immediately without requiring institutional support.

By contrast, the strategies illustrated in Figure 8b—such as diversification of economic activities, planting coastal vegetation, mobilizing family members to work, or strengthening fishers' institutions—are used far less frequently (generally below 30%). These measures demand higher financial resources, longer-term commitment, or institutional coordination, which are often beyond the reach of small-scale fishermen. As a result, although these strategies could potentially enhance resilience, their adoption remains limited compared to the more accessible short-term coping strategies shown in Figure 8a.

5.3 Modelling Adaptation of Small-Scale Fishermen to Climate Change

Poverty and livelihood vulnerability are two distinct concepts, yet their interrelationship is evident in the key dimension of livelihood vulnerability in poverty assessments. The livelihood vulnerability of fishermen is closely tied to poverty levels and low adaptive capacity. Climate change, which often exacerbates poverty and increases vulnerability, significantly impacts fishers. Therefore, this research aimed to develop a model to analyze the impact of poverty and livelihood vulnerability on the climate change adaptation strategies employed by fishermen in the Bengkulu coastal area.

The extent of resource ownership by fishermen significantly affects their ability to adopt climate change adaptation measures. It is believed that the degree of poverty and vulnerability experienced by fishermen directly impacts their capacity to implement effective adaptation strategies. Two key processes were conducted to evaluate the structural equation model (SEM) in this research: (a) Assessing the overall model fit, Goodness of Fit, to evaluate the effectiveness of the model in representing the observed data; and (b) Testing hypotheses and analyzing the relationship of variables to determine the extent and significance of their influence on each other.

Table 3 demonstrates that the route analysis equation has a satisfactory model fit, meeting the overall criterion. This suggests that there is no substantial disparity between the covariance matrix of the observed variables and that of the proposed model, as indicated by the data. In this context, the model equation used in route analysis could effectively elucidate the relationships and impact between the dependent and independent variables. The structural equation derived from the route analysis results obtained from the fit model in Table 3 can be constructed using the AMOS output in Regression Weights. Specifically, the equation can be generated as follows:

$$Adaptation\ (Y) = -\beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 - \beta_{LVI} LVI - \beta_{MPI} MPI + \beta_{PI} PI + e_1$$

Table 3. Results of goodness-of-fit path analysis

Goodness of Fit Measure	Fit Value Indicator	Results of Analysis	Status
Chi-square	Getting smaller	24.937	Good
Probability	≥ 0.05	0.204	Good
CMIN/DF	≤ 2.00	1.247	Good
GFI	≥ 0.90	0.980	Good
AGFI	≥ 0.90	0.933	Good
RMSEA	≤ 0.08	0.034	Good
TLI	≥ 0.90	0.971	Good
CFI	≥ 0.90	0.989	Good

Table 4. Estimated values of the influence of each variable on the adaptation of fishermen

Influence of the Variables	Expected Sign	Estimated Values	*P*
Adaptation (TA) ← Age (X1)	-	-0.001	0.071*
Adaptation (TA) ← Formal education (X2)	+	0.000	0.871
Adaptation (TA) ← Fishing experience (X3)	+	0.002	0.004***
Adaptation (TA) ← Household size (X4)	-	0.006	0.382
Adaptation (TA) ← Ship weight (X5)	+	0.004	******
Adaptation (TA) ← Fishing distance (X6)	+	0.004	******
Adaptation (TA) ← Fishing gear (X7)	+	0.022	0.045**
Adaptation (TA) ← Livelihood vulnerability (LVI)	-	-0.151	0.217
Adaptation (TA) ← Poverty (MPI)	-	-0.171	0.034**
Adaptation (TA) ← Climate change understanding (PI)	+	0.001	0.272

Note: ***significant at α = 1%; ** significant at α = 5%; *significant at α = 10%

The estimated values of the influence of each variable and their significance are presented in Table 4. The results of covariance output in Table 5 show the loading factor and critical ratio (*C.R.*) values for each indicator that reflects a variable. It is known that the values of the indicators in the path analysis model are valid because they have loading factor values > 0.50 and significant values where the *C.R.* ⩾ 2.00 or *P* < 0.1, indicated by a *** sign.

Table 5. Estimated values of the loading factor and the critical ratio relationship between independent variables in path analysis

Variable Correlation	Loading Factor (Estimate)	*C.R.*	*P*
Climate change understanding (PI) ↔ Poverty (MPI)	0.131	1.860	0.063
Climate change understanding (PI) ↔ Livelihood vulnerability (LVI)	-0.071	-1.355	0.175
Poverty (MPI) ↔ Livelihood vulnerability (LVI)	0.000	0.136	0.892
Fishing gear (X7) ↔ Climate change understanding (PI)	2.132	3.637	***
Fishing distance (X6) ↔ Livelihood vulnerability (LVI)	0.062	1.789	0.074
Fishing distance (X6) ↔ Fishing gear (X7)	-1.162	-2.957	0.003
Ship weight (X5) ↔ Livelihood vulnerability (LVI)	0.254	5.076	***
Ship weight (X5) ↔ Climate change understanding (PI)	39.927	4.407	***
Ship weight (X5) ↔ Fishing gear (X7)	2.363	4.413	***
Age (X1) ↔ Livelihood vulnerability (LVI)	0.231	5.008	***
Age (X1) ↔ Poverty (MPI)	0.247	3.393	***
Age (X1) ↔ Climate change understanding (PI)	-15.968	-2.121	0.034
Age (X1) ↔ Fishing gear (X7)	-1.599	-3.410	***
Formal education (X2) ↔ Poverty (MPI)	-0.110	-4.710	***
Formal education (X2) ↔ Age (X1)	-11.722	-5.091	***
Fishing experience (X3) ↔ Livelihood vulnerability (LVI)	0.170	3.800	***
Fishing experience (X3) ↔ Poverty (MPI)	0.241	3.191	0.001
Fishing experience (X3) ↔ Climate change understanding (PI)	-25.725	-3.395	***
Fishing experience (X3) ↔ Fishing gear (X7)	-1.759	-3.676	***
Fishing experience (X3) ↔ Ship weight (X5)	-7.956	-1.571	0.116
Fishing experience (X3) ↔ Age (X1)	87.971	9.068	***
Fishing experience (X3) ↔ Formal education (X2)	-16.587	-6.504	***
Household size (X4) ↔ Poverty (MPI)	0.036	4.096	***
Age (X1) ↔ Fishing distance (X6)	-5.223	-0.970	0.332
Fishing experience (X3) ↔ Fishing distance (X6)	5.430	1.054	0.292

Note: ***significant at α = 1%

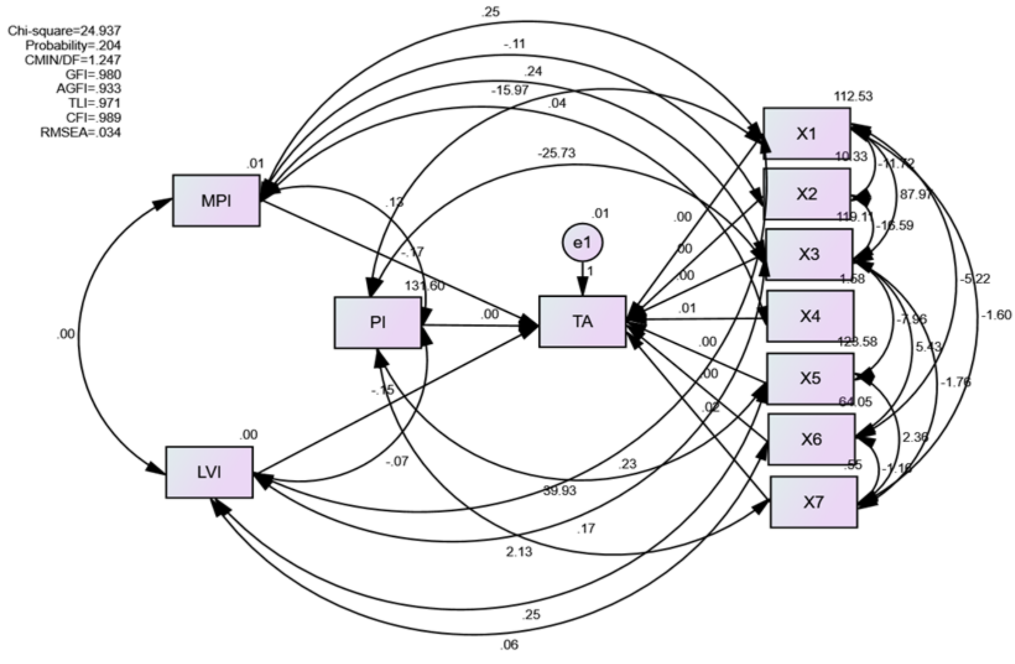


Figure 9. Model of the influence of poverty, livelihood vulnerability, and understanding of climate change on the level of adaptation of fishermen

The analysis of the path analysis equation model in Figure 9 reveals that the estimated parameter for the impact of fishermen's poverty level on the level of climate change adaptation is -0.171. The *C.R.* value is 2.125, which exceeds the threshold of 2.00 (> 2.00), indicating statistical significance at a 5% significance level or a *P* value of 0.034. The null hypothesis (H_0) is rejected, thus indicating that poverty significantly and negatively affects the level of climate change adaptation among fishermen. There is an inverse relationship between poverty levels, as measured by the MPI, and the extent of climate change adaptation practices implemented by the fishermen.

6. Discussion

6.1 Multidimensional Poverty of Small-Scale Fishermen

Small-scale fishermen in Bengkulu Province are among the poorest rural groups, and their poverty is multidimensional rather than purely monetary. Limited education, low access to health services, restricted employment alternatives, and weak access to capital reinforce poverty traps that hinder livelihood improvement. The multidimensional poverty perspective (Alkire & Santos, 2014) emphasizes that overlapping deprivations exacerbate vulnerability, which explains why fishermen remain poor even when their incomes increase seasonally. Climate change exacerbates poverty by increasing operational costs, reducing fish availability, and creating uncertainty in weather patterns. Under such conditions, fishermen adopt only the most affordable coping strategies, such as adjusting their fishing times and shifting their fishing grounds. These strategies are consistent with findings in other regions, where poverty is a critical factor limiting the capacity of coastal communities to undertake long-term adaptation (Cinner et al., 2018; Xu et al., 2023).

The persistence of poverty among Bengkulu fishermen also reflects the persistence of structural and historical inequalities. For instance, most households rely solely on fishing for subsistence and are unable to accumulate savings to invest in vessel upgrades or alternative livelihoods. Similar findings were reported in small-scale fisheries in Africa and South Asia, where poverty traps are perpetuated by lack of access to credit and weak government support (Cinner et al., 2018; Daw et al., 2009). Poverty also intersects with demographic factors: larger household sizes increase dependency ratios, thereby diluting household income and reinforcing vulnerability (Nurkse, 1953; Nurwati, 2008). Furthermore, low levels of education—where the majority of respondents had only completed elementary school—restrict mobility into other sectors and limit awareness of climate-related risks. As Ananda et al. (2007) emphasize, low educational attainment directly constrains access to stable employment, health, and food security, thereby perpetuating intergenerational poverty.

Thus, the multidimensional poverty experienced by fishermen in Bengkulu not only reduces their ability to respond to environmental shocks but also shapes the kinds of adaptation strategies they can realistically adopt. Rather than pursuing transformative measures, they are forced into reactive and low-cost strategies, such as shifting fishing grounds or reducing fishing days. These findings align with those of Xu et al. (2023) and van Noordwijk et al. (2016), who note that poverty and resource dependence often lead communities toward short-term responses that maintain survival but do not necessarily enhance long-term resilience.

6.2 Livelihood Vulnerability of Small-Scale Fishermen

Livelihood vulnerability in Bengkulu emerges from high dependence on fisheries, weak diversification, and limited technical capacity. The vulnerability index indicates that economic and technical aspects—such as income reliance on fishing, small vessel size, and restricted fishing range—contribute most strongly to risk exposure. Socio-cultural constraints, including low educational attainment and reliance on traditional knowledge, further limit adaptive responses. These findings align with studies in other small-scale fisheries, where livelihood vulnerability is exacerbated by ecological shocks combined with weak institutional support (Cinner et al., 2018; Pomeroy et al., 2006). Climate change increases vulnerability by reducing fish stocks, damaging ecosystems, and amplifying risks from extreme weather (Carron et al., 2021; IPCC, 2014).

The measurement results of the LVI also reflect varying levels of vulnerability across exposure, sensitivity, and adaptive capacity. Indicators such as fishery income (0.899) and the number of active fishermen (1.000) fall into the very high vulnerability category, indicating that households remain heavily dependent on daily catches for survival. Cinner et al. (2018) and Xu et al. (2023) similarly found that dependence on capture fisheries without livelihood diversification greatly amplifies vulnerability during shifts in fishing seasons or declines in catch. This condition is evident in traditional communities in Kaur and Mukomuko Regencies, where limited fleet capacity prevents fishers from venturing further offshore.

Moderate vulnerability indicators, such as the number of trips (0.574), boat power (0.409), and fishing experience (0.481), illustrate technical and demographic barriers to adaptation. Smaller vessels with limited gross tonnage reduce mobility and safety, particularly during extreme weather events in the Indian Ocean. These constraints align with findings by Pomeroy et al. (2006), who noted that technological limitations often exacerbate climate risks for small-scale fishermen. Conversely, indicators such as non-fishery income (0.097) and fishing income for operational costs (0.202) fall into the low or very low categories, suggesting some opportunities for diversification. Cinner et al. (2018) and Daw et al. (2009) argue that household-level diversification into fish processing, trade, or even non-fisheries work is a key pathway for reducing vulnerability.

Geophysical factors also intensify vulnerability. Coastal erosion in South and North Bengkulu, with rates of 2–3 meters per year, has resulted in the loss of fishing grounds and the intrusion of saltwater into coastal agricultural land (Pandu, 2020). This environmental degradation not only reduces catch but also undermines household food security. Fishermen report withered coastal vegetation, which further accelerates erosion and limits ecosystem-based adaptation options. Combined with low institutional support, these ecological pressures create a situation in which fishers remain highly vulnerable but are unable to mobilize the necessary resources for effective adaptation.

The gender dimension of vulnerability is equally significant. Women, though central in post-harvest processing and marketing, face limited access to credit, training, and decision-making spaces. This reduces household resilience and constrains families' capacity to diversify income sources. Atteridge & Remling (2018) emphasize that including women in adaptation planning strengthens livelihood outcomes and ensures more equitable resilience. In Bengkulu, empowering women through access to cooperatives and microfinance could therefore play a critical role in reducing overall vulnerability.

Overall, the situation of small-scale fishermen in Bengkulu illustrates that livelihood vulnerability is concentrated in economic dependence, technological limitations, and institutional weaknesses. Without substantial intervention in these areas, fishermen will remain trapped in cycles of poverty and vulnerability, with climate change further intensifying their precarious livelihoods.

6.3 Modelling Adaptation of Small-Scale Fishermen to Climate Change

The structural equation model highlights the interrelationship between poverty, livelihood vulnerability, and adaptation among small-scale fishermen in Bengkulu. The results indicate that poverty and vulnerability negatively affect adaptation, while vessel capacity, fishing distance, and gear diversity significantly improve adaptive capacity. Interestingly, fishing experience was found to correlate with higher poverty, indicating that long-term dependence on traditional fishing methods may reinforce vulnerability rather than reduce it. This finding resonates with the concept of “poverty traps” in climate-sensitive communities, where accumulated experience does not automatically translate into resilience without adequate assets or institutional support (Milman & Warner, 2016).

These results suggest that adaptation is shaped not only by ecological and technical conditions but also by socioeconomic and institutional contexts. Fishermen with better assets—larger vessels, diversified gear, and greater access to capital—were more likely to adopt proactive strategies, while poorer households relied on reactive, short-term coping mechanisms. This reflects broader patterns identified by Cinner et al. (2018) and Xu et al. (2023), who argue that poverty directly constrains the capacity of small-scale fishers to shift from coping to adaptation. Cinner et al. (2018) and Pomeroy et al. (2006) similarly observed that resource-poor fishing communities tend to remain dependent on familiar practices, even when such practices may become maladaptive under changing climate conditions.

The model also confirms the role of education and generational differences in shaping adaptation. Fishermen with higher levels of education were more likely to access information, engage with cooperatives, and diversify livelihoods, thereby reducing their dependence on capture fisheries. By contrast, older fishermen with decades of experience tended to persist with traditional methods, often due to cultural attachment and lack of alternative skills. This duality reflects the argument of Daw et al. (2009), who emphasize that both social capital and human capital are critical in determining adaptation pathways. In the Bengkulu context, education serves not only as a protective factor but also as a bridge toward more innovative and resilient adaptation practices.

From a methodological perspective, integrating MPI and LVI into the SEM framework provides a holistic understanding of how socioeconomic and ecological pressures interact to shape adaptation. This approach adds empirical depth to the literature by simultaneously capturing both structural constraints and adaptive responses. While previous studies often assessed poverty, vulnerability, or adaptation separately, this study demonstrates that they must be analyzed in relation to one another to understand the dynamics of resilience in small-scale fisheries.

From a policy perspective, the results highlight that adaptation among Bengkulu fishermen remains reactive mainly. Adjusting fishing grounds or times may help households cope in the short term, but these strategies do not address the underlying causes of poverty and vulnerability. Without institutional support—such as cooperatives, access to credit, modernized fleets, or extension services—fishermen risk being locked into cycles of reactive adaptation that may eventually become maladaptive. Antwi-Agyei et al. (2018) caution that maladaptation can arise when short-term strategies reduce vulnerability in the present but increase risks in the future, for example, by overexploiting nearshore resources or reinforcing dependence on unstable fisheries.

Overall, the modelling results confirm that poverty alleviation, livelihood diversification, and institutional strengthening are essential to move fishermen from coping to genuine adaptation. In line with Pomeroy et al. (2006) and Xu et al. (2023), this study underscores that adaptation cannot be viewed solely as an individual or technical process but must be supported by broader social, economic, and governance interventions. Strong cooperatives and government assistance could strengthen adaptive capacity by enhancing resource availability and collective action (Béné et al., 2016; Gupta et al., 2010; Nti et al., 2021). Thus, integrating poverty reduction into adaptation planning is not only a welfare concern but also a prerequisite for building resilience in climate-vulnerable coastal communities.

7. Conclusions and Policy Implications

This study contributed to the theoretical and methodological development of research on climate change adaptation by integrating poverty and livelihood vulnerability into the analysis of fishermen's adaptive capacity. Unlike numerous previous studies that focused solely on exposure and sensitivity, the approach in this paper highlighted how socioeconomic constraints, particularly poverty and dependence on fishing income, directly shaped adaptation strategies. This article advanced the methodological tools, LVI, and their linkage with the outcomes of adaptation, to assess the resilience of small-scale fisheries in the context of developing countries.

The current study illustrated that fishermen in Bengkulu Province mainly relied on reactive strategies, such as changing fishing areas and adjusting fishing times. These responses, while common, remain insufficient in the absence of institutional and financial support. It was discovered that poverty was a significant limiting factor, whereas vessel capacity and fishing distance were positively associated with greater adaptation. This demonstrates the importance of combining socioeconomic and technical variables in explaining adaptation behavior.

From the policy perspective, strengthening resilience requires participatory and locally grounded interventions. First, empowering local economic institutions, such as fishermen cooperatives, savings and loan groups, and microfinance organizations, could improve access to credit, reduce individual risks, and enable investments in vessel modernization and diversified livelihoods. Second, strengthening social capital through fishermen's associations and community-based organizations could facilitate collective action, knowledge sharing, and the integration of local ecological knowledge into adaptation planning. Finally, government programs should adopt a more participatory approach by involving fishermen in decision-making processes to ensure that policies align with local realities, cultural practices, and the actual needs of coastal communities.

By emphasizing the interaction between poverty, vulnerability, and adaptation, this article not only extended theoretical insights into climate change adaptation but also provided practical guidance for participatory and context-specific policy design in small-scale fisheries. Strengthening both economic and social institutions at the community level is crucial for ensuring that fishermen in Bengkulu and other similar regions can develop sustainable resilience against the impacts of climate change.

Author Contributions

Conceptualization, G.M. and I.C.; methodology, G.M., I.C. and I.; software, G.M.; validation, G.M., I.C., I. and A.I.H.; formal analysis, G.M. and I.C.; investigation, A.I.H.; resources, G.M., I.C. and I.; data curation, I.C and I.; writing—original draft preparation, G.M., I.C., I. and A.I.H.; writing—review and editing, G.M., I.C. and I.; visualization, G.M. and A.I.H.; supervision, I.; project administration, G.M.; funding acquisition, G.M. All authors have read and agreed to the published version of the manuscript.

Funding

This work is funded by the Ministry of Education, Culture, Research, and Technology in Indonesia (Grant No.: 3939/UN30.15/PT/2024).

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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