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Climate Adaptation and Livelihood Resilience in Shaping Food Security among Coastal Seaweed Farming Households in Indonesia

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ABSTRACT

Adequate food consumption in households within coastal areas does not necessarily reflect a state of robust food security, particularly regarding access to food—especially when these communities face climate change and challenges to their livelihoods.. This research examines how adaptive capacity, livelihood resilience, and coping strategies relate to two aspects of food security: food insecurity experience and household food consumption. A quantitative cross-sectional survey of 251 seaweed-farming households along the northern coasts of Serang and Tangerang in Banten Province was conducted, and data from 248 respondents were included in the final analysis. The five key variables studied are adaptive capacity (ADAPT), Livelihood Resilience Index (LRI), Coping Strategies Index (CSI), Food Consumption Score (FCS), and Food Insecurity Experience Scale (FIES). Analysis was performed using observed-variable Structural Equation Modeling (SEM) with 5,000 bootstrap samples. The results indicate that adaptive capacity enhances livelihood resilience, and both are associated with a lower experience of food insecurity. Conversely, higher intensity of coping strategies correlates with greater food insecurity experience. The FIES model accounts for 53.6% of the variation in food insecurity, while the FCS model explains only 7.1% of the variation in food consumption. Mediation through livelihood resilience and coping strategies was significant in the FIES model; however, serial mediation was not. These findings highlight that apparent adequate food consumption does not always indicate freedom from food access issues. The study emphasizes the need for complementary food security indicators to inform policies that bolster coastal communities' livelihood resilience.

Keywords: *Climate adaptation; Livelihood resilience; Food insecurity experience; Coping strategies; Seaweed farming; Coastal households.*

INTRODUCTION

Climate change is one of the multidimensional challenges facing the livelihood viability and food security of coastal communities. Climate change—including shifts in temperature and seasons, extreme weather events, and disruptions to marine ecosystems—can directly or indirectly affect production, income, and households' access to food. These impacts depend not only on the intensity of environmental disturbances but also on a household's ability to manage risks and sustain its livelihood. Therefore, food security results from interactions among environmental conditions, adaptive capacity, livelihood resilience, and household socio-economic dynamics. (Béné et al., 2016; Tendall et al., 2015).

Seaweed is a key export commodity for Indonesia, accounting for approximately 30% of global production (FAO, 2026). For coastal communities in Indonesia, seaweed farming is a vital economic activity, providing income, employment, and opportunities for livelihood diversification. Its relatively simple cultivation methods, low capital requirements, and short production cycles make it well-suited for small-scale producers. However, its economic contribution does not always translate into stable well-being; environmental dependence, price fluctuations, limited

market access, and production uncertainty can increase farming households' vulnerability. Research by (Rimmer et al., 2021) indicates that the socioeconomic benefits of seaweed farming in Indonesia are closely linked to productivity, institutional support, and value chain development.

Adaptive capacity is crucial for managing such uncertainty. It enables households to adjust their economic activities and mitigate the impact of disruptions. This capacity encompasses the ability to use resources, access information, adjust production, and develop alternative livelihoods. However, adaptive capacity is not synonymous with livelihood resilience (Speranza et al., 2014). Livelihood resilience involves buffering capacity, self-organization, and learning, which enable households to maintain their livelihood functions when facing stress. Thus, adaptive capacity may contribute to livelihood resilience, though the relationship between the two requires empirical testing. Livelihood resilience is also linked to a household's ability to maintain access to food. Households with diverse resources, social networks, and livelihood options may have more room to adjust when facing disruptions. Conversely, limited assets and reliance on a single income source can increase the need to employ survival strategies. However, the relationship between resilience and food security is not always direct, as households can maintain consumption through various adjustment mechanisms.

Coping strategies are actions households take when facing food shortages or difficulty affording food. These include using savings, borrowing, credit purchases, or reducing meal portions or frequency. (Maxwell et al., 2008) state that the Coping Strategies Index (CSI) assesses these actions by their frequency and severity. However, not all coping strategies indicate successful adaptation; some may temporarily sustain consumption, while others highlight increasing strain on household well-being. Additionally, adequate food consumption does not always equate to food security. Discrepancies in food security measurement arise because indicators reflect different aspects of the issue. The Food Consumption Score (FCS) measures dietary patterns based on food group consumption frequency, whereas the Food Insecurity Experience Scale (FIES) assesses access issues, from concerns about food sufficiency to actual intake reduction. (Cafiero et al., 2018) note that FIES is based on people's lived experiences. These differences demonstrate that observing adequate food consumption alone does not fully capture the food-access challenges households face.

Households can maintain relatively adequate consumption frequency through borrowing, social assistance, savings, or other coping strategies. Consequently, households with adequate FCS may still experience food insecurity according to the FIES. This is significant for research on coastal communities, as fluctuating incomes can strain food access even before consumption levels show a marked decline. Therefore, using FCS and FIES together enables a more comprehensive assessment of food security than relying on a single indicator.

Several studies have developed frameworks for food system resilience, livelihood resilience, and measuring food insecurity. (Tendall et al., 2015) developed a conceptual framework for food system resilience that integrates social, economic, and biophysical dimensions, while (Speranza et al., 2014) proposed a livelihood resilience indicator framework emphasizing buffer capacity, self-organization, and learning. In the context of measuring food insecurity, (Maxwell et al., 2008) analyzed data from 14 surveys to evaluate coping strategies as indicators of food insecurity. Meanwhile, (Cafiero et al., 2018) described the development of the FIES as an instrument for measuring the experience of food insecurity, and (Jones et al., 2013) demonstrated the importance of understanding the distinct

dimensions measured by various food security indicators. (Rimmer et al., 2021) examined how seaweed farming contributes to the livelihoods and well-being of Indonesian communities. (Gibson et al., 2021) explained that seemingly adequate food consumption can coexist with food insecurity and household coping strategies, as measured by the Food Consumption Score (FCS) and the Household Food Insecurity Access Scale (HFIAS) using a generalized linear mixed model analysis. (Kpadé et al., 2023) sought to integrate resilience, FIES, and CSI in a study of agricultural cooperative members during the pandemic; however, their research did not focus on seaweed farmers or the five variables used in the present study. (Amadu et al., 2021) used SEM to study 1,180 small-scale fishers in Ghana and test and validate a livelihood resilience framework based on buffering capacity, self-organization, and learning. This study serves as a close methodological comparator for LRI and SEM within the context of coastal livelihoods. However, it differs in that it focuses on resilience formation and does not compare FCS and FIES as two distinct outcomes.

(Toiba et al., 2024) examined the relationship between climate change adaptation strategies and household food security among 445 shrimp farmers. This research reinforces the link between adaptation and food security in Indonesia's aquaculture sector. However, it did not employ SEM, nor did it compare mechanisms involving LRI and CSI with FCS and FIES. (Egamberdiev et al., 2024) explored household resilience and coping strategies in the context of food insecurity; their study used SEM to construct a resilience index and analyze interrelationships among resilience dimensions. While this article offers an important point of comparison—demonstrating how SEM can link resilience components—its analysis did not incorporate the five specific variables used in the present study. Finally, (Killa et al., 2026) analyzed 300 households in East Sumba using SEM to examine relationships among disaster experience, social capital, social protection, and adaptive capacity regarding climate risk; however, that study did not integrate CSI, FCS, and FIES into its food security model.

Previous research has examined climate adaptation, livelihood resilience, coping strategies, and household food insecurity; however, these aspects are generally investigated in isolation or within fragmented analytical frameworks. There is limited evidence regarding the connection between adaptive capacity, livelihood resilience, coping behaviors, and various household food insecurity indicators within a comprehensive structural framework, particularly among coastal seaweed-farming households. This study addresses that gap by exploring the pathways linking adaptive capacity, livelihood resilience, and coping strategies to food consumption and experiences of food insecurity.

This research utilizes data collected from seaweed-farming households located along the northern coast of Banten, Indonesia. A total of 251 households were surveyed, with 248 complete observations included in the combined analysis. Employing structural equation modeling (SEM), the study investigates both the direct and indirect relationships among adaptive capacity, livelihood resilience, coping strategies, and two distinct food security indicators analyzed independently. The objectives of the study are to: (1) explore the associations between adaptive capacity, livelihood resilience, and coping strategies; (2) evaluate the mediating roles of livelihood resilience and coping strategies in the relationship between adaptive capacity and food security; and (3) compare the structural relationships and the explanatory power of the FCS and FIES models. The scientific contribution of this research resides in integrating the livelihood resilience framework with multidimensional food security assessments, thereby

elucidating how households involved in seaweed farming may exhibit adequate food consumption concurrently with constraints in food access.

2. Material and Methods

2.1 Theoretical Framework Development

Adaptive capacity and livelihood resilience are interrelated yet distinct concepts for explaining a household's ability to cope with climate change and various socio-economic pressures. (Engle, 2011) defines adaptive capacity as a system's ability to anticipate and prepare for stressors and changes, or to adjust to and respond to the impacts caused by such stressors. Meanwhile, resilience tends to focus heavily on processes, interactions, and reciprocal relationships within socio-ecological systems. (Siders, 2019) explains that adaptive capacity is multidimensional, determined by a combination of assets, knowledge, technology, institutions, social networks, and decision-making capabilities. For coastal communities, this capacity is particularly crucial because marine-resource-based livelihoods are highly sensitive to environmental changes, climate variability, and anthropogenic pressures (Ferro-Azcona et al., 2019). According to (Mutanda & Nhamo, 2026), livelihood resilience in coastal communities is the capacity of individuals or communities to persist, recover, and adapt to environmental (natural) and anthropogenic (human-induced) stressors that threaten their natural-resource-based livelihoods. Their research analyzes livelihood resilience using three primary frameworks: the Sustainable Livelihoods Framework—applied to coastal resilience and encompassing shocks, trends, and seasonality; the double exposure framework—highlighting how coastal communities are exposed to combined global threats such as climate change; and the five components of adaptive capacity identified by (Cinner et al., 2018)—namely asset building, learning, social organization, flexibility, and agency. Their research demonstrates that coastal communities are not passive. To survive, they use adaptation strategies categorized into two main types: intra-sectoral changes (adaptation within the same sector) and inter-sectoral changes (diversification into different sectors).

(Speranza et al., 2014) operationalize livelihood resilience through three key dimensions: buffer capacity, self-organization, and capacity for learning. This approach has been applied to small-scale fishing communities; for instance, (Amadu et al., 2021) used SEM on 1,180 fishers in Ghana to demonstrate the relevance of these three dimensions in explaining coastal communities' livelihood resilience. Conceptually, adaptive capacity can be viewed as a foundation for building resilience, as the ability to access resources, learn, innovate, and adjust strategies enhances a household's capacity to cope with disruptions. However, the two concepts should remain distinct, as adaptive capacity does not invariably lead to resilient livelihood outcomes (Nyamwanza, 2012; Siders, 2019). Based on this reasoning, the present study proposes the following hypothesis:

H1: Adaptive capacity is positively associated with the livelihood resilience of seaweed farming households.

(Thulstrup, 2015) explains adaptive capacity and livelihood resilience as integrated components of the Sustainable Livelihood Approach (SLA). The study concludes that diversifying livelihood portfolios through capital mobilization is the key driver of adaptive capacity. Households that do not diversify—relying solely on a single non-forestry livelihood—face the highest risk as natural disasters become more frequent. While adaptive capacity,

livelihood resilience, and coping strategies all describe household responses to stress, they operate across different time horizons and mechanisms. Adaptive capacity reflects a relatively long-term ability to anticipate, adjust to, and transform livelihood strategies in the face of environmental and socio-economic changes. Access to human capital, productive resources, information, technology, social networks, and institutional services shapes this capacity. For instance, (Chisale et al., 2024) show that human capital, institutional services, and social networks shape a community's capacity to respond to extreme climate events. Thus, adaptation is not merely a post-disruption response; it also reflects the capacity to prepare for and sustain livelihoods in the face of recurring risks.

This concept differs from coping strategies, which primarily reflect household responses to ongoing stress or scarcity. In the context of food insecurity, coping strategies may include switching to cheaper or less preferred foods, reducing meal portions and frequency, borrowing food or money, purchasing food on credit, or relying on assistance from relatives. Coping strategies in the context of food security have been shown to effectively address food access pressures during crises (Budiawati, Natawidjaja, Sarwo Utomo, et al., 2024). Recent evidence indicates that consumption-based strategies are primarily employed as short-term solutions when food access is disrupted (Biadgilign, 2023). However, the boundary between coping and adaptation is not always absolute. Some initially temporary responses can evolve into long-term strategies, whereas repeated coping—particularly selling productive assets or reducing investment in health and education—can erode a household's capacity to withstand future shocks (Debessa et al., 2022). Livelihood resilience lies between these two processes, reflecting a household's ability to absorb shocks, adjust, and maintain livelihood functions without a prolonged decline in well-being. Studies (Egamberdiev et al., 2024) show that resilience capacity and coping strategies need to be analyzed concurrently as both relate to food security, while resilience can also mitigate the negative impacts of shocks on household food conditions. Findings from China further indicate that household resilience—encompassing absorptive, adaptive, and transformative capacities—is linked to household consumption and dietary diversity (X. Han et al., 2024).

This distinction is particularly relevant for seaweed-farming households. Theoretically, stronger adaptive capacity enables households to make adjustments before stress escalates into a consumption crisis, whereas livelihood resilience helps preserve resources and economic functions when disruptions occur. Conversely, intensified coping strategies may indicate that a household is struggling to meet its food needs. A study in Nepal shows that adaptation strategies are positively associated with food security, while coping indicators capture short-term responses to food insecurity. Accordingly, this study treats adaptive capacity and resilience as capacities that can theoretically reduce reliance on food coping strategies, rather than as concepts synonymous with coping (Kandel et al., 2024). Based on this conceptualization, the hypotheses proposed in this study are:

H2: Adaptive capacity is negatively associated with the intensity of household coping strategy use.

H3: Livelihood resilience is negatively associated with the intensity of household coping strategy use.

Household food security results from the interplay among the ability to cope with change, sustain livelihoods, and respond to food-related pressures. In this study, we hypothesize that adaptive capacity (ADAPT), Livelihood Resilience (LRI), and Coping Strategies (CSI) are associated with food security; however, these relationships may

Food security varies depending on the indicators used to measure it. In this context, we focus on the access dimension. using the Food Insecurity Experience Scale (FIES) and the consumption (utility) dimension using the Food Consumption Score (FCS). This distinction matters because FIES measures limited food access due to resource constraints, whereas FCS reflects the frequency, diversity, and relative value of consumed food groups. Thus, the two metrics capture related yet distinct dimensions of food security (Frongillo, 2022; Jubayer et al., 2023).

Theoretically, higher adaptive capacity strengthens a household's ability to maintain food access and consumption through livelihood diversification, use of information, production adjustments, and access to resources. Evidence from small-scale fishers in Indonesia links climate change adaptation to improved food security, as measured by both FIES and FCS; similar positive associations have been observed among Indonesian shrimp-farming households and smallholder farmers in Nepal (Kandel et al., 2024; Rahman et al., 2022). Research by (Budiawati, Natawidjaja, Perdana, et al., 2024) shows that coping strategies influenced food security, as measured by FIES, during the COVID-19 crisis. Furthermore, livelihood resilience provides the capacity to absorb shocks and sustain household economic functions; conceptually, this should reduce food insecurity while supporting food consumption.

Conversely, a high intensity of coping strategies may reflect escalating pressure on food access. Households may maintain consumption levels by borrowing, buying food on credit, cutting other expenses, or changing their diets. Consequently, coping strategies may be more strongly associated with food insecurity than with observed consumption. Recent studies also indicate that consumption and coping indicators can yield differing estimates of food security status (Danso-Abbeam et al., 2023; Kandel et al., 2024; Mbhenyane et al., 2025). Accordingly, it is necessary to examine FIES and FCS separately to determine whether these three determinants show consistent patterns of association across the two dimensions of food security. Based on this conceptual framework, the study proposes the following hypotheses:

H4a–H4b: Adaptive capacity is negatively associated with FIES and positively associated with FCS.

H5a–H5b: Livelihood resilience is negatively associated with FIES and positively associated with FCS.

H6a–H6b: Coping strategy intensity is positively associated with FIES and negatively associated with FCS.

The relationship between adaptive capacity and food security is not necessarily direct; it can operate through changes in a household's ability to sustain its livelihood and the responses used when facing food-related stress. Livelihood resilience is the primary mechanism through which adaptive capacity translates into the ability to absorb shocks, maintain assets and income sources, and meet basic needs. Recent literature indicates that adaptive capacity is a key component of resilience capacity and that higher resilience is associated with better food security outcomes (Egamberdiev et al., 2024). Thus, we hypothesize that adaptive capacity influences FIES and FCS indirectly through LRI.

A second mechanism operates through coping strategies. When adaptive resources cannot fully absorb stress, households may resort to short-term measures such as borrowing, buying food on credit, or reducing meal frequency and quantity. Empirical evidence shows that coping strategies are short-term responses closely linked to food security

status, so they should be analyzed alongside resilience capacity (Egamberdiev et al., 2024). Therefore, ADAPT is also hypothesized to relate to food security indirectly through CSI.

A third mechanism proposes serial mediation: higher adaptive capacity improves livelihood resilience, which diminishes the need for intensive coping strategies. These changes in coping behaviors are then connected to food security. Conceptually, this forms a continuum—ADAPT → LRI → CSI → food security—rather than separate responses. Nevertheless, this serial relationship is an empirical hypothesis that requires testing and cannot be presumed to be true automatically. Therefore, the mediation hypothesis suggested is:

H7a ADAPT → LRI → FIES	*Mediating effect via LRI*
H7b ADAPT → LRI → FCS	*Mediating effect via LRI*
H8a ADAPT → CSI → FIES	*Mediating effect via CSI*
H8b ADAPT → CSI → FCS	*Mediating effect via CSI*
H9a ADAPT → LRI → CSI → FIES	*Serial mediation*
H9b ADAPT → LRI → CSI → FCS	*Serial mediation*

The conceptual framework of this study is shown in Figure 1 below:

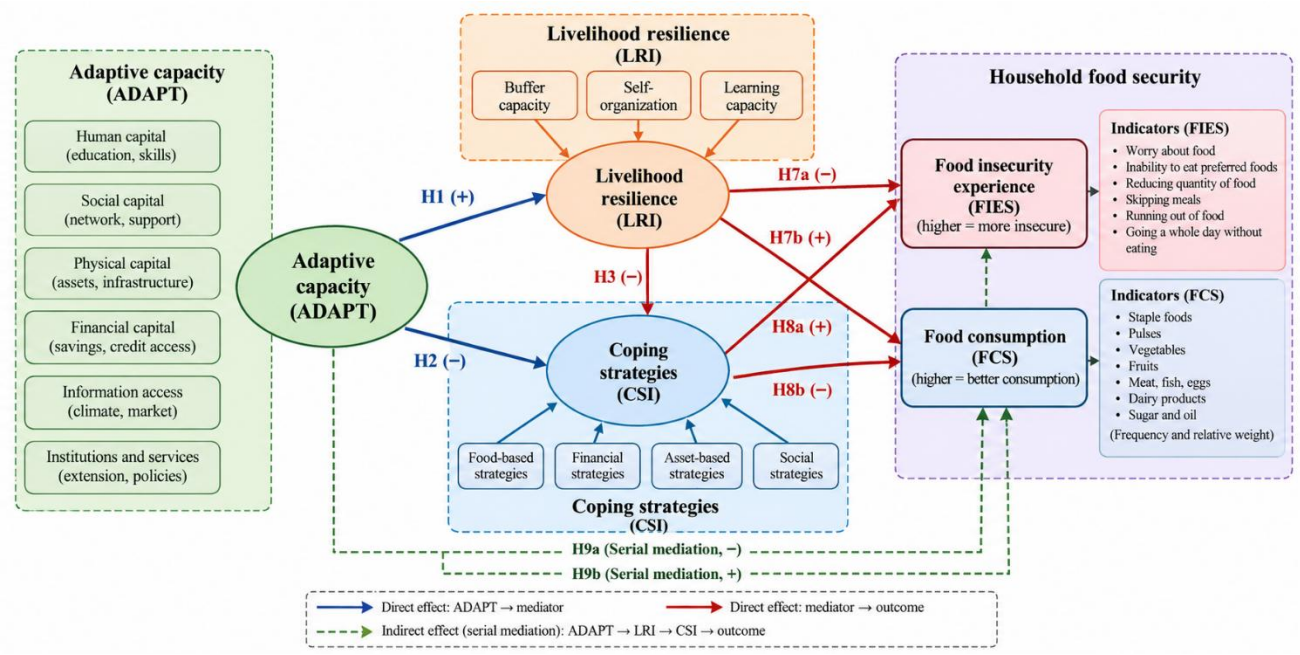

Figure 1 Research conceptual framework adopted from (S. Han et al., 2024)

2.2 Study Area, Research Design and Sampling

The research was conducted in the northern coastal areas of Banten Province, specifically in Serang Regency and Tangerang Regency. These locations were selected because both areas are centers for seaweed farming in Banten Province. In 2022, Banten Province ranked 13th among seaweed producers in Indonesia (Figure 2).

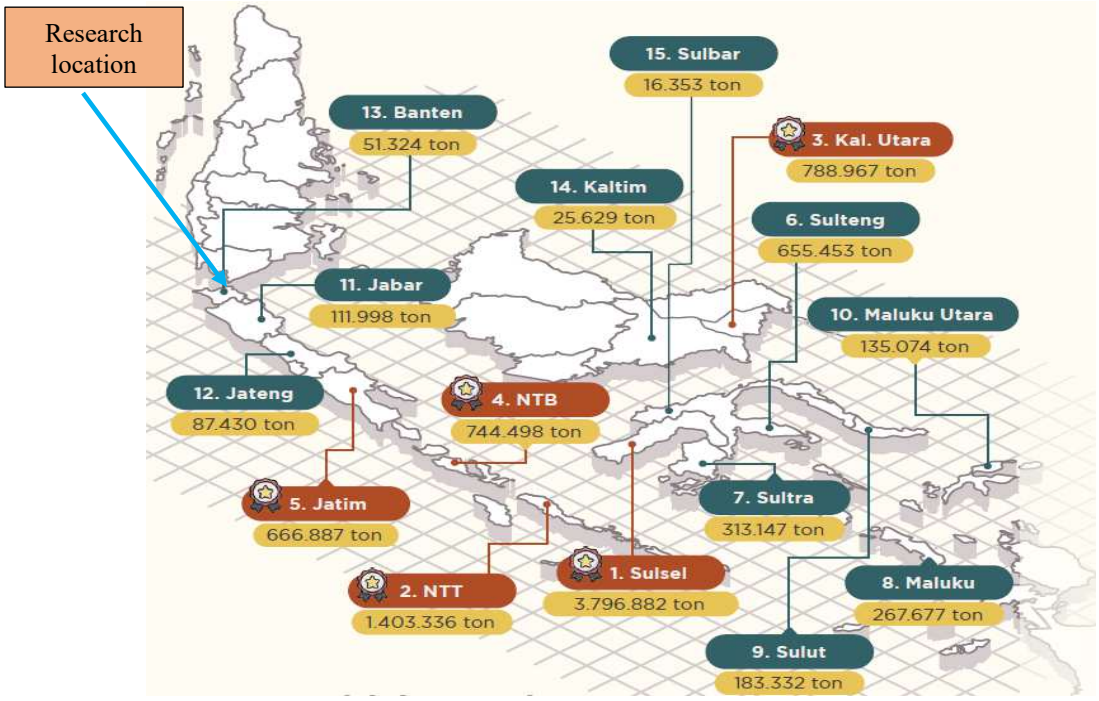

Figure 2. Seaweed production hub regions in Indonesia (Source: Ministry of Marine Affairs and Fisheries of the Republic of Indonesia, 2023)

These regions support coastal fishing and aquaculture, which are vital to the community's livelihoods. We used simple random sampling across these two areas, yielding a total of 251 seaweed-farming households. In Serang Regency, 209 households were selected: 1 from Pontang Village, 36 from Tangkurak Village, 92 from Domas Village, 51 from Lontar Village, and 29 from Barangbang Village. In Tangerang Regency, 42 seaweed-farming households were selected, consisting of 39 from Kronjo Village and 5 from Kemiri Village. Data on the number of seaweed farmers were obtained from the Marine and Fisheries Agencies of Serang Regency and Tangerang Regency.

A comparison of the number of farming households in this study is presented in Figure 3 below:

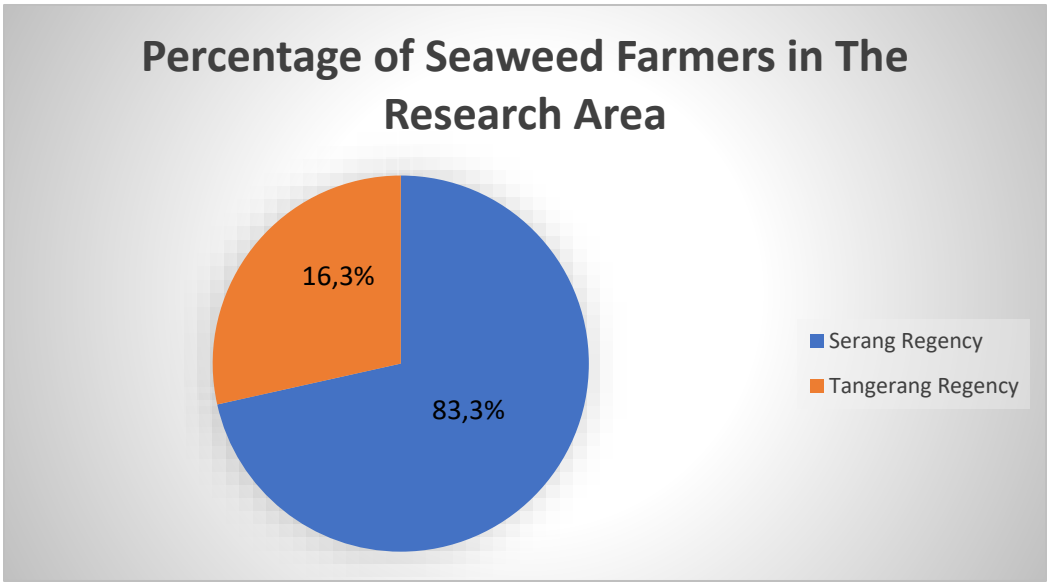

Figure 3. Percentage of Seaweed Farmers in The Research Area

Previous research shows that seaweed farming in the study area remains a vital economic activity for coastal communities, despite declining production and challenges related to technology, the environment, and business development (Gumilar et al., 2024; Saputra et al., 2024). Tangerang Regency also has significant potential for coastal commodities; besides seaweed, it supports microalgae species (Faridj et al., 2025). We chose these two areas to reflect the diversity of socio-economic conditions and livelihoods among seaweed-farming households along Banten's northern coast. The study employed a cross-sectional survey, gathering data in a single observation period. The study focused on seaweed-farming households, assessing their adaptive capacity, livelihood resilience, coping strategies, food consumption, and household-level experiences of food insecurity.

2.3 Data Collection

The respondent unit comprised household members with direct knowledge of farming activities and the household's socioeconomic conditions. Data collection used structured interviews with a questionnaire covering household characteristics, adaptive capacity (ADAPT), livelihood resilience (LRI), coping strategies (CSI), food consumption (FCS), and food insecurity experience (FIES). We interviewed 251 respondents in the initial survey. After screening for completeness, we excluded three respondents from the combined analysis due to incomplete FIES data, leaving a final analytic sample of 248 households (complete-case analysis).

Although the survey sample size was 251, we used 248 observations to analyze the relationships among ADAPT, LRI, CSI, FCS, and FIES. The complete-case analysis approach is appropriate when the analysis requires complete data for all variables under study, though patterns and proportions of missing data must still be reported transparently.

2.4 Measurement of Research Variables

Five household-level variables capture adaptive capacity (ADAPT), Livelihood Resilience (LRI), Coping Strategies (CSI), Food Insecurity (FIES), and Food Consumption (FCS). These variables were defined as observed composite measures used in the subsequent path analysis.

Adaptive capacity (ADAPT) was measured using six household-level items rated on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). These items assessed households' ability to acquire relevant knowledge and information, modify seaweed-farming practices, access external support, and implement technological or livelihood adjustments in response to climatic and livelihood disturbances. We computed a composite score by summing responses to the six items and converting the total to a 0–100 scale, representing the percentage of the maximum possible score. Higher scores indicate greater adaptive capacity. The ADAPT score formula is based on:

$$\text{ADAPT}_{\text{raw i}} = \sum_{j=1}^{6} ADAPT_{ij}$$

$$\bar{}\text{ADAPTi} = \frac{\sum_{j=1}^{6} ADAPT_{ij}}{6}$$

The index used in SEM is :

$$\text{ADAPTi} = \frac{\sum_{j=1}^{6} ADAPT_{ij}}{6} \text{ x } 100$$

Livelihood resilience (LRI) was measured using six five-point Likert items that assess households' capacity to maintain livelihood functions and respond to disturbances. This conceptualization was informed by the livelihood-resilience framework of (Speranza et al., 2014), which emphasizes buffer capacity, self-organization, and learning capacity. We treated the six indicators as equally weighted components and aggregated them into a composite score. The resulting score was transformed to a 0–100 scale, expressed as a percentage of the maximum attainable score. Higher LRI values therefore indicate stronger livelihood resilience. The formula for calculating the LRI score is derived from:

$$\text{LRI}_{\text{raw i}} = \sum_{j=1}^{6} LRI_{ij}$$

$$\bar{\bar{}}\text{LRIi} = \frac{\sum_{j=1}^{6} LRI_{ij}}{6}$$

The index used in SEM is :

$$\text{LRIi} = \frac{\sum_{j=1}^{6} LRI_{ij}}{6} \text{ x } 100$$

We assessed household coping responses using the Coping Strategies Index (CSI). Seven coping strategies, retained from the questionnaire, were integrated using severity weights that mirror the relative intensity of each response. We aggregated the weighted frequency scores to derive the household CSI. Consequently, higher CSI values indicate a greater dependence on, and a higher severity of, coping responses to household food-related stress. The CSI methodology effectively captures the behavioral responses households use when challenged to secure adequate food (Maxwell et al., 2008).

Two complementary measures evaluate household food security. The Food Insecurity Experience Scale (FIES) captures households' experiences of limited food access during the reference period through eight occurrence questions. Affirmative responses are summed to produce a raw score ranging from 0 to 8, with higher scores indicating more severe food-insecurity experiences. The structural model employs the raw score as the continuous observed

outcome. The Food Consumption Score (FCS) assesses household food consumption over the previous seven days. The questionnaire records consumption by food item from Day 1 to Day 7, enabling the determination of consumption frequency at the food-group level. Within each food group, consumption on a given day is counted once if at least one item from that group is consumed, regardless of the number of items. Consequently, the food-group frequency ranges from 0 to 7 days. Frequencies are multiplied by standard FCS weights and then summed to produce the total FCS, with higher scores indicating greater frequency and diversity of food consumption according to the FCS metric. Table 1 below presents the definitions and operationalizations of the variables used in this study.

Table 1 Definitions and Operationalization of Variables

Variable	Measurement	Range/Scoring	Interpretation	Sources
ADAPT	Composite adaptive-capacity index	0–100	Higher score = greater adaptive capacity	(Mesfin et al., 2020)
LRI	Composite livelihood-resilience index	0–100	Higher score = greater livelihood resilience	(Speranza et al., 2014)
CSI	Weighted frequency of seven coping strategies	Weighted score	Higher score = more intensive/severe coping	(Maxwell et al., 2008)
FIES	Sum of affirmative responses to eight experience-based items	0–8	Higher score = more severe experienced food insecurity	(Cafiero et al., 2022)
FCS	Seven-day food-group consumption frequency × standard food-group weights	Weighted score	Higher score = better food-consumption frequency and diversity	(Wiesmann et al., 2009)

2.5 Statistical Analysis

We conducted statistical analysis in Jamovi using a sequential procedure that included data screening, descriptive analysis, preliminary association testing, structural model estimation, and mediation analysis. Figure 4 summarizes the analytical workflow.

Stage 1: Data screening and descriptive analysis. We first examined the dataset for completeness and consistency. A total of 251 households participated in the survey; however, we excluded three observations with incomplete FIES information from the combined analysis, resulting in an analytical sample of **248 households**. We calculated descriptive statistics, including means, standard deviations, ranges, and frequency distributions, for ADAPT, LRI, CSI, FIES, and FCS. We also examined the distributions of food-security indicators and the frequency and intensity of household coping strategies.

Stage 2: Preliminary association and diagnostic assessment. We estimated Pearson correlation coefficients to examine the direction and strength of bivariate associations among the study variables. We also assessed multicollinearity using correlations and variance inflation factors (VIF). We examined residual diagnostics and distributional characteristics because the data showed departures from normality. Non-normality matters in covariance-based SEM because it can affect standard errors, test statistics, and model-fit measures under conventional maximum-likelihood estimation (Jobst, 2022).

Stage 3: Structural model estimation. Two separate structural models were estimated using maximum likelihood (ML). Model 1 specified FIES as the household food-security outcome, whereas Model 2 specified FCS as the outcome. In both models, ADAPT, LRI, and CSI were entered as observed composite indices, rather than latent constructs. Consequently, the procedure is more precisely described as covariance-based SEM/path analysis using observed variables, rather than PLS-SEM. ML estimation is supported within the *lavaan* SEM framework.

Stage 4: Direct and mediation-effect testing. The analysis estimated direct effects, specific indirect effects, total indirect effects, and total effects. Three mediation mechanisms were evaluated: ADAPT → LRI → outcome; ADAPT → CSI → outcome; and the serial pathway ADAPT → LRI → CSI → outcome. We based our statistical inference for indirect effects on 5,000 bootstrap resamples with 95% confidence intervals, reducing reliance on the normality assumption for the sampling distribution of indirect effects. Bootstrap estimation of defined indirect parameters is supported in lavaan.

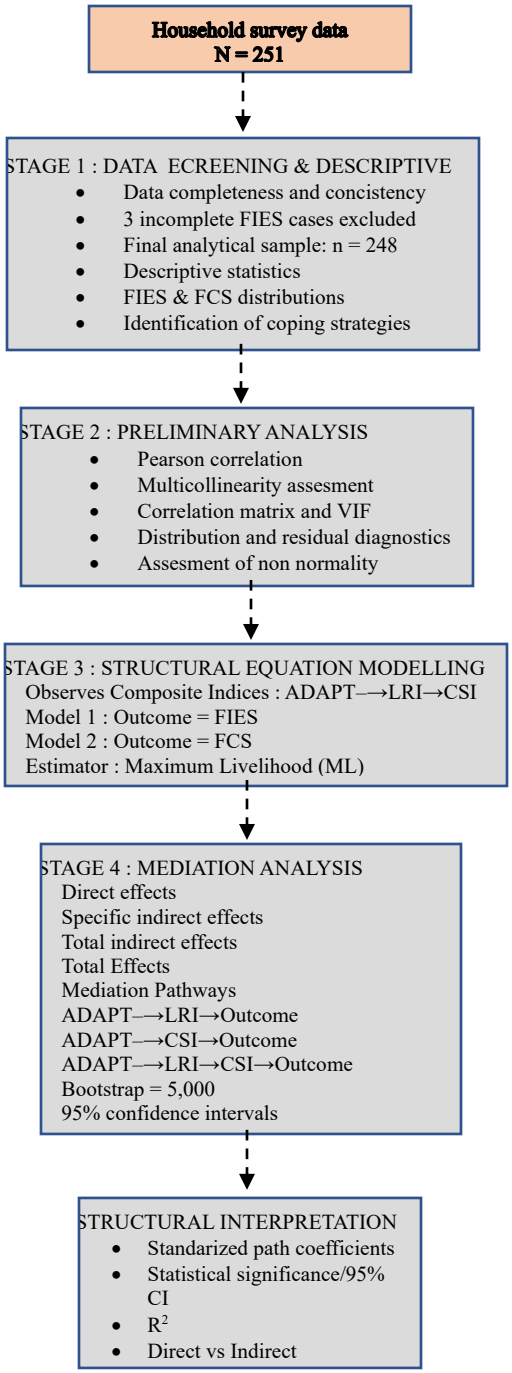

Figure 4. Analytical workflow for examining the relationships among adaptive capacity, livelihood resilience, coping strategies, and household food-security outcomes.

3. RESULT

3.1 Socio-Demographic Characteristics of Seaweed Farming Households

The socio-demographic characteristics of the respondents provide an overview of the baseline conditions of households engaged in seaweed farming within the study area. This information matters because factors such as age, education, business experience, household size, livelihood diversification, and income levels can influence a household's ability to respond to environmental and economic changes and sustain livelihoods. This study analyzed respondent characteristics, including age, gender, seaweed farming experience, household size, education level, livelihood diversification (or supplementary employment), and monthly household income. We used frequency distributions and percentages to describe categorical variables, while numerical variables were summarized using means, medians (where relevant), and minimum and maximum values. Table 2 presents a summary of the socio-demographic characteristics of the 251 respondents.

Table 2. Socio-Demographic Characteristics of Seaweed Farming Households

Characteristics	**Category**	**n**	**%**
Age (years)	20–34	7	2,8
	35–44	22	8,8
	45–54	90	35,9
	55–64	111	44,1
	≥65	21	8,4
	Total	**251**	**100**
	Average	**54,29**	
	Min	**22**	
	Max	**73**	
Gender	Man	237	94,4
	Woman	14	5,6
Experience as a seaweed farmer (years)	≤5	25	10,0
	6–10	91	36,3
	11–15	104	41,3
	16–20	21	8,4
	>20	10	4,0
	Total	**251**	**100**
	Average	**11,22**	
	Min	**2**	
	Max	**35**	
Household size	1–3 people	72	28,7
	4–5 people	145	57,8
	≥6 people	34	13,5
	Total	**251**	**100**
	Average	**4,10**	
	Min	**1**	

	Max	**14**	
Education	No attending school	11	4,4
	Elementary school	154	61,4
	Junior high school	41	16,3
	Senior high school	44	17,5
	Bachelor	1	0,4
	Total	**251**	**100**
Livelihood Diversification/Extra Job	Yes	201	80,1
	No	45	17,9
	Cannot be determined	5	2,0
	Total	**251**	**100**
Household income per month	< 83,85 USD	85	33,9
	83,85 USD – < 139,75 USD	106	42,2
	139,75 USD – < 223,26 USD	52	20,7
	≥ 223,26 USD	8	3,2
	Total	**251**	**100**
	Average	**165,20 USD**	
	Min	**50,31 USD**	
	Max	**6.708,22 USD**	
	Median	**83,85 USD**	

Socio-demographic characteristics indicate that respondents were predominantly male (94.4%), with a mean age of 54.29 years. Most (80.1%) were aged 45–64. Respondents had extensive experience in seaweed farming, averaging 11.22 years, with 77.7% engaged for 6–15 years. Formal education levels were relatively low; 61.4% of respondents had only primary school education, while a small minority had pursued upper secondary or higher education. The average household size was approximately 4.10 individuals, with the majority (57.8%) comprising 4–5 members.

Livelihood diversification was a predominant characteristic among respondents. Approximately 80.1% of households engaged in supplementary employment or income-generating activities, including fishing, pond management, trading, small retail establishments, or other service-oriented occupations. This suggests that the majority of households did not depend solely on a single economic activity but rather integrated seaweed cultivation with various alternative livelihood sources. Household income exhibited considerable variation, with a median of IDR 1.50 million and an average of IDR 2.96 million per month, ranging from IDR 0.90 million to IDR 120 million. Notably, exceptionally high income levels were primarily associated with respondents whose principal occupation involved serving as seaweed intermediaries, a role entailing larger-scale commercial transactions compared to those

of seaweed cultivators. Overall, this demographic profile reflects households equipped with substantial business experience and considerable diversification of livelihoods, albeit characterized by an aging population and limited educational attainment.

3.2 Household Adaptive Capacity, Livelihood Resilience, and Food Security

Adaptive capacity is the ability of seaweed farming households to adjust their farming-based livelihoods in response to environmental and market risks, as well as climate change (Soto & Garcia Sampaio, 2025). In this study, the ADAPT variable represents adaptive capacity. Livelihood resilience (LRI) is defined as the ability of a household to recover from shocks (Speranza et al., 2014). The LRI variable is defined as a household's ability to maintain its livelihood and recover after facing environmental, weather-related, or economic shocks. The results of the descriptive statistical analysis for ADAPT and LRI are presented in Table 3 below:

Table 3 Descriptive Statistics Results for the ADAPT and LRI Variable

Statistic	ADAPT	LRI
Total households	251	251
Minimum Score	11	14
Maximum Score	27	30
Average Score	17,53	19,36
Average Index 0 - 100	58,45	65,54

Source : Primary data analysis

Among the 251 respondents, the initial average ADAPT index was approximately 58.45 on a 0–100 scale, while the average LRI index was around 64.54. A construct audit revealed that the six-indicator reflective model was not fully adequate, particularly for ADAPT. The initial Cronbach's alpha values were 0.543 for ADAPT and 0.812 for LRI. The average index values—58.45 for ADAPT and 65.54 for LRI—place the subjects in the moderate resilience category according to the study's operational classification. This indicates that seaweed farmers in Banten Province, in the aggregate, have the ability to adapt to change and stress, though this capacity is neither sufficiently robust nor evenly distributed. While seaweed farming households possess some capacity to respond to climate change and livelihood disruptions, this capacity remains moderate and is thus insufficient to provide full protection against various external pressures.

Regarding the Coping Strategy Index (CSI), the fundamental concept of CSI analysis employed in this study is the one developed by (Maxwell et al., 2008). This concept assesses the frequency and severity of strategies employed by households to cope with food shortages. A higher CSI score indicates greater vulnerability and poorer household food security. The results of the statistical analysis of the CSI are presented in Table 4 below:

Table 4 Descriptive Statistics for CSI Analysis

CSI Statistics	Value
N	251
Mean	15,96
Median	18,00
SD	10,27
Minimum	0,00
Maximum	43,50
CSI = 0	30,00
CSI > 0	221,00

Source : Primary data analysis

The total CSI score of 251 in the table indicates that the majority of households had employed at least one of the coping strategies recorded in this research instrument. Table 5 below presents the coping strategies adopted by seaweed farming households to deal with various pressures and changes regarding food access:

Table 5 Number of Households Employing Types of Coping Strategies

Coping Strategy	Number of Respondents	%
Eating at a friend's or neighbor's house	111	44,22
Using savings/pension funds	78	31,08
Voucher/token/electronic money	3	1,20
In debt to the shop/greengrocer	175	69,72
Reducing the amount of food	203	80,88
Reducing the frequency of eating	193	76,89
Skipping a meal / not eating that day	44	17,53
Total	**251**	**100**

Source : Primary data analysis

The findings indicate that the most dominant coping strategies employed by seaweed-farming households are reducing food intake and cutting meal frequency to 1–2 times per day; consequently, food-related stress within these households is primarily manifested through adjustments to food quantity (80.88%) and meal frequency (76.89%), rather than solely through financial mechanisms.

The Food Consumption Score reflects household dietary diversity or patterns over the past seven days; the final score is classified into three categories: poor, borderline, or acceptable. The results of the descriptive statistical analysis are presented in Table 6 below:

Table 6 Descriptive Statistics of Household Food Consumption Scores for Seaweed Farmers

FCS Statistics	Value
N	251
Mean	50,34
Median	50,50
SD	7,62
Minimum	17,50
Maximum	66,50
Skewness	-0,957
Excess kurtosis	2,393

Source : Primary data analysis

Based on the classification used by the WFP, the FCS is categorized into "poor," "borderline," and "acceptable" levels. The results of the FCS calculations for the 251 respondents are presented in Table 7 below:

Table 7 FCS Classification of Seaweed-Farming Households

Category	n	Percentage
Poor	2	0,80%
Borderline	7	2,79%
Acceptable	242	96,41%
Total	251	100%

Source : Primary data analysis

The results indicate that the respondents' household food consumption levels were generally favorable based on the Food Consumption Score (FCS) indicator. The mean FCS was 50.34 ± 7.62, with a median of 50.50. The proximity of the mean to the median suggests that the center of the FCS distribution is relatively consistent.

A total of 242 households (96.41%) fell into the "acceptable" food consumption category, 7 households (2.79%) were in the "borderline" category, and 2 households (0.80%) were in the "poor" category. Thus, only 9 out of 259 households fell below the "acceptable" category. The FCS reflects the frequency and diversity of food consumption. An "acceptable" FCS generally signifies good and adequate food consumption, though it does not necessarily guarantee a diverse diet or dietary variety. In-depth analysis revealed a left-skewed (negative) distribution, meaning the majority of respondents were concentrated at relatively high FCS levels, while a small number of households with low FCS scores formed a left-hand tail. A kurtosis value of 2.393 indicates a leptokurtic distribution; thus, the FCS distribution is not perfectly symmetrical or normal. There were 24 respondents (9.56%) statistically classified as outliers; the majority belonged to the "poor" category (with FCS scores of 17.5 and 20.0), while others had high FCS scores (64.5 and 66.5). The following figure 5 shows the distribution of FCS scores among 251 seaweed-farming households.

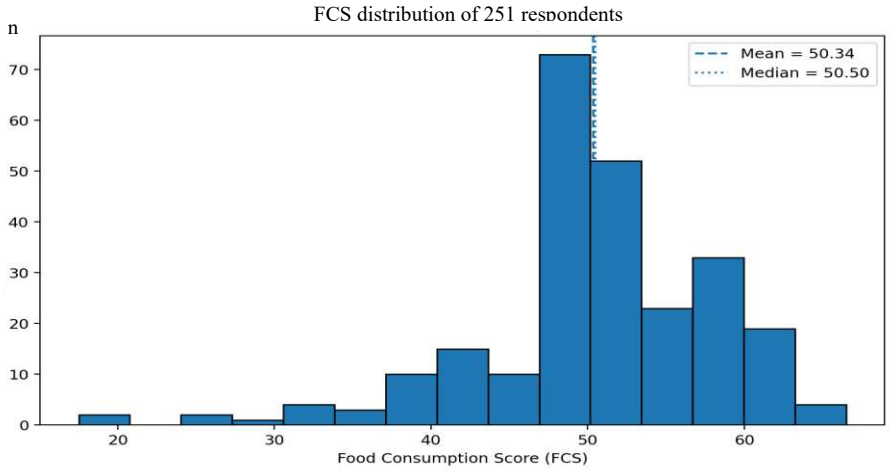

Figure 5 FCS Distribution of Seaweed Farming Households

The results of the FCS analysis for the eight major food groups are presented in Table 8 below.

Table 8 Contribution Magnitude and FCS Percentage of Seaweed-Farming Households by Major Food Group

Food Group	Average Frequency	Weight	FCS Contribution	Average % FCS
Meat/Fish/Egg	5,44	4	21,77	43,24%
Staples	7,00	2	14,00	27,81%
Pulses	2,79	3	8,37	16,62%
Sugar	6,78	0,5	3,39	6,74%
Vegetables	2,72	1	2,72	5,41%
Fruits	0,06	1	0,06	0,12%
Milk/Derivatives	0,01	4	0,03	0,06%
Oil/Fat	0,00	0,5	0,00	0,00%

Source : Primary data analysis

According to these findings, three food groups—meat, fish, eggs, staples, and pulses—comprise approximately 87.7% of the average Food Consumption Score (FCS). This reflects a specific household consumption pattern among seaweed farmers, wherein these three groups are consumed daily. This pattern is likely attributable to the availability of fish, seafood, and eggs as accessible sources of protein for these coastal farming communities.

Despite the high FCS, dietary diversity within certain food groups remains very low. Specifically, 94.02% of households reported no fruit consumption, 99.6% reported no dairy consumption, and 100% reported no oil/fat consumption. Conversely, 85.66% of respondents reported a sugar consumption frequency of seven. This shows that an "acceptable" FCS does not necessarily indicate a diverse diet or optimal nutritional quality; the high score is driven by staple foods and animal proteins rather than a balanced, varied intake across all food groups.

Regarding the Food Insecurity Experience Scale (FIES) calculation, out of 251 respondents, 248 had valid FIES data, while 3 had incomplete data or were non-respondents. The mean raw FIES score was 4.23 (median: 5.00; SD: 1.99; minimum: 0; maximum: 7). The distribution of raw FIES scores is presented in Table 9 below:

Table 9 Distribution of FIES Raw Scores

FIES Raw Score	(n)	Percentage (%)
0	12	4,84
1	25	10,08
2	16	6,45
3	18	7,26
4	43	17,34
5	75	30,24
6	23	9,27
7	36	14,52
8	0	0,00
Total	**248**	**100**

Source : Primary data analysis

Table 9 shows that, on average, respondents experienced approximately 4.23 of the eight food insecurity experiences surveyed. The higher the raw score, the greater the severity of the food insecurity experienced. The FAO indicates that higher scores reflect more severe food insecurity. The results of the FIES score analysis are presented in Table 10 below:

Table 10 Analysis of FIES Scores and Category Distribution among Seaweed-Farming Households

Description of Raw-score FIES	n	Percentage from 248 Valid
Food secure (0)	12	4,84%
Mild (1–3)	59	23,79%
Moderate (4–6)	141	56,85%
Severe (7–8)	36	14,52%
Total	**248**	**100%**

Source : Primary data analysis

Meanwhile FCS values—where 96.41% of respondents fell into the "acceptable" category—the FIES classification reveals a different picture: 71.37% of valid respondents (177 individuals) experienced moderate to severe food insecurity.

3.3 Correlations among The Study Variabless

Pearson correlation analysis was conducted to evaluate the bivariate relationships among adaptive capacity (ADAPT), livelihood resilience (LRI), coping strategies (CSI), Food Consumption Score (FCS), and Food Insecurity Experience Scale (FIES) for 248 households with complete data. Based on the correlation results for the 248 respondents with complete data, Table 11 present the Pearson correlations between the variables in this study.

Table 11 Pearson Correlation Matrix Among Research Variables (N = 248)

Variabel	ADAPT	LRI	CSI	FCS	FIES
ADAPT	1,000	0,816*	-0,363*	-0,097	-0,631*
LRI	0,816*	1,000	-0,278*	-0,222*	-0,600*
CSI	-0,363*	-0,278*	1,000	0,005	0,541*
FCS	-0,097	-0,222*	0,005	1,000	0,179
FIES	-0,631*	-0,600*	0,541*	0,179	1,000

Note : * p < 0,001; ** p < 0,01; * p < 0,05.

The results indicate a strong positive correlation between ADAPT and LRI ($r = 0.816$; $p < 0.001$). ADAPT is negatively correlated with CSI ($r = -0.363$) and FIES ($r = -0.631$), while LRI is also negatively correlated with CSI ($r = -0.278$) and FIES ($r = -0.600$). Conversely, CSI shows a relatively strong positive correlation with FIES ($r = 0.541$), suggesting that the more intensive the coping strategies employed by households, the higher their experience of food insecurity. Correlations between FCS and most other variables are relatively weak, including with ADAPT ($r = -0.097$) and CSI ($r = 0.005$), while its correlation with FIES is $r = 0.179$.

The high correlation between ADAPT and LRI warrants attention when interpreting the structural model, as it indicates a strong empirical link between the two constructs. However, a correlation of 0.816 does not in itself imply that the two are identical variables. Given that both serve as composite indices conceptually representing distinct capacities, path coefficients involving ADAPT and LRI must be interpreted with caution rather than as representing entirely independent effects. This pattern supports the rationale for treating FCS and FIES as two separate outcomes rather than combining them into a single food security measure. As a complementary analysis, a cross-tabulation of FCS and FIES—showing the distinct differences between the two indicators—is presented in Table 12 below.

Table 12 Cross-Tabulation Results between FCS and FIES

FCS \ FIES	Food secure	Mild FI	Moderate FI	Severe FI	Total
Poor	0	0	2	0	2
Borderline	0	0	7	0	7
Acceptable	12	59	132	36	239
Total	**12**	**59**	**141**	**36**	**248**

Source : Primary data analysis

The most notable finding from the analysis is that 168 households exhibited an "acceptable" Food Consumption Score (FCS) yet experienced moderate to severe food insecurity according to the Food Insecurity Experience Scale (FIES). This figure represents 67.74% of the 248 valid household records, or 70.29% of the 239 households with an "acceptable" FCS. These results indicate that relatively adequate food consumption can coexist with difficulties in accessing food. Furthermore, all nine households with "poor" to "borderline" FCS scores fell into the moderate food insecurity category.

Substantively, this pattern suggests that some households are able to maintain consumption levels by adjusting expenditures or leveraging social networks, assets, savings, debt, or other coping strategies. This explanatory hypothesis will subsequently be tested using Coping Strategy Index (CSI) data and structural modeling. The next step is a descriptive statistical analysis of the combined CSI-FIES data to observe the patterns that emerge. Table 13 below presents the descriptive statistics for this combination:

Table 13 Combined CSI-FIES Descriptive Statistical Analysis

FIES Category	n	Mean CSI	Median CSI	CSI > 0
Food Secure	12	7,00	3,75	58,33%
Mild	59	8,95	9,00	71,19%
Moderate	141	18,53	18,00	97,16%
Severe	36	21,67	22,50	94,44%

Source : Primary data analysis

The table above reveals a clear, progressive pattern: food secure (7.00) → mild (8.95) → moderate (18.53) → severe (21.67). The differences in CSI across the four FIES categories are also statistically significant according to the Kruskal-Wallis test ($H = 63.33$; $p < 0.001$). This provides empirical evidence that CSI and FIES move consistently as indicators of food stress or vulnerability, even though they measure different aspects. Previous analysis found that while the FCS fell into the "acceptable" category, the FIES status ranged from moderate to severe. Table 14 below presents the relevant results:

Table 14 Comparative Analysis of FCS Groups and CSI Scores

Category	n	Mean CSI	Median CSI	CSI > 0	CSI ≥ median total (18)
FCS acceptable + FIES secure/mild	71	8,62	7,50	69,01%	23,94%
FCS acceptable + FIES moderate/severe	168	19,34	18,00	96,43%	70,24%
FCS poor/borderline	9	16,00	14,00	100%	44,44%

Source : Primary data analysis

Based on the data, the 168 households with acceptable food consumption but moderate/severe FIES status had an average CSI of 19.34. In contrast, the 71 households with acceptable FCS and secure/mild FIES status had an average CSI of only 8.62. This difference is substantial (10.72 points); effectively, the CSI of the first group was approximately 2.24 times that of the second group. The difference in distribution between the two groups was also highly significant according to the Mann-Whitney test ($U = 9{,}606$, $p < 0.001$).

3.4 Structural Relationships in The FIES Model

The structural model using the **FIES** as the food-security outcome revealed several significant relationships among adaptive capacity, livelihood resilience, coping strategies, and household food insecurity. The result show in Tabel 15 below :

Table 15 Structural Path Estimates for Model A with FIES as the Outcome (N = 248)

Structural relationship	B	SE	95% CI	β	z	*p*	Result
ADAPT → LRI	1.1092	0.04667	[1.0187, 1.2020]	**0.8156**	23.768	<0.001	Significant (+)
ADAPT → CSI	−0.3266	0.09776	[−0.5146, −0.1330]	**−0.4046**	−3.341	<0.001	Significant (−)
LRI → CSI	0.0306	0.06783	[−0.1024, 0.1651]	0.0516	0.451	0.652	Not significant
ADAPT → FIES	−0.0433	0.01112	[−0.0647, −0.0211]	**−0.2745**	−3.888	<0.001	Significant (−)
LRI → FIES	−0.0318	0.00751	[−0.0460, −0.0167]	**−0.2747**	−4.240	<0.001	Significant (−)
CSI → FIES	0.0713	0.00995	[0.0510, 0.0905]	**0.3653**	7.165	<0.001	Significant (+)

Explained variance: R^2(LRI) = **0.665**; R^2(CSI) = **0.132**; R^2(FCS) = **0.071.**
Notes: B = unstandardized coefficient; SE = standard error; CI = confidence interval; β = standardized coefficient. ADAPT = Adaptive Capacity Index; LRI = Livelihood Resilience Index; CSI = Coping Strategies Index; FIES = Food Insecurity Experience Scale. Higher FIES scores represent greater severity of experienced food insecurity.

The Table 15 showed that Adaptive capacity (ADAPT) was strongly and positively associated with livelihood resilience (LRI) (β = 0.816, $p < 0.001$), indicating that households with greater adaptive capacity tended to exhibit higher livelihood resilience. ADAPT explained **66.5% of the variance in LRI (R^2 = 0.665)**. ADAPT was also negatively associated with coping strategies (CSI) (β = −0.405, $p < 0.001$), suggesting that households with greater adaptive capacity reported less intensive reliance on coping strategies. In contrast, the direct relationship between LRI and CSI was small and statistically non-significant (β = 0.052, $p = 0.652$). Together, ADAPT and LRI explained **13.2% of the variance in CSI (R^2 = 0.132)**. The non-significant LRI–CSI pathway is noteworthy given the strong relationship between ADAPT and LRI, indicating that LRI did not contribute a statistically distinguishable association with coping strategies once ADAPT was simultaneously included in the model.

For the primary outcome, both ADAPT (β = −0.275, $p < 0.001$) and LRI (β = −0.275, $p < 0.001$) were negatively associated with FIES. Thus, greater adaptive capacity and livelihood resilience were independently associated with lower levels of experienced food insecurity. Conversely, CSI showed a positive association with FIES (β = 0.365, $p < 0.001$), indicating that greater reliance on coping strategies was associated with more severe food-insecurity experiences. Collectively, ADAPT, LRI, and CSI explained **53.6% of the variance in FIES (R^2 = 0.536)**.

3.5 Structural Relationships in The FCS Model

The structural model using the **Food Consumption Score (FCS)** as the food-security outcome produced a markedly different pattern from the FIES model. The result of structural relationship in the FCS model show in Tabel 16 below :

Table 16 Structural Path Estimates for Model B with FCS as the Outcome (N = 248)

Structural relationship	B	SE	95% CI	β	z	*p*	Result
ADAPT → LRI	1.1092	0.0467	[1.0186, 1.2021]	**0.8156**	23.757	<0.001	Significant (+)
ADAPT → CSI	−0.3266	0.0977	[−0.5145, −0.1327]	**−0.4046**	−3.342	<0.001	Significant (−)
LRI → CSI	0.0306	0.0678	[−0.1025, 0.1651]	0.0516	0.452	0.651	Not significant
ADAPT → FCS	0.1464	0.0814	[−0.0069, 0.3110]	0.2419	1.797	0.072	Not significant
LRI → FCS	−0.1898	0.0531	[−0.2976, −0.0856]	**−0.4265**	−3.574	<0.001	Significant (−)
CSI → FCS	−0.0196	0.0444	[−0.1065, 0.0675]	−0.0261	−0.441	0.659	Not significant

Explained variance: R^2(LRI) = **0.665**; R^2(CSI) = **0.132**; R^2(FCS) = **0.071**.
Notes: B = unstandardized coefficient; SE = standard error; CI = 95% confidence interval; β = standardized coefficient. ADAPT = Adaptive Capacity Index; LRI = Livelihood Resilience Index; CSI = Coping Strategies Index; FCS = Food Consumption Score.

The structural model using the **Food Consumption Score (FCS)** as the outcome showed a substantially different pattern from that observed in the FIES model. Adaptive capacity (ADAPT) was strongly and positively associated with livelihood resilience (LRI) (β = 0.816, $p < 0.001$), explaining **66.5% of the variance in LRI (R^2 = 0.665)**. ADAPT was also negatively associated with coping strategies (CSI) (β = −0.405, $p < 0.001$), whereas the relationship between LRI and CSI was small and statistically non-significant (β = 0.052, $p = 0.651$). Together, ADAPT and LRI explained **13.2% of the variance in CSI (R^2 = 0.132)**.

For the food-consumption outcome, ADAPT showed a positive but statistically non-significant direct association with FCS (β = 0.242, $p = 0.072$; 95% CI [−0.007, 0.311]). In contrast, LRI was significantly and negatively associated with FCS (β = −0.427, $p < 0.001$; 95% CI [−0.298, −0.086]). This negative coefficient indicates that, conditional on ADAPT and CSI, greater livelihood resilience was associated with a lower FCS. Given the strong association between ADAPT and LRI, we should interpret this counterintuitive conditional relationship cautiously and examine it further in the Discussion. CSI, meanwhile, was not significantly associated with FCS (β = −0.026, $p = 0.659$).

Overall, the three predictors explained only 7.1% of the variance in FCS (R^2 = 0.071). This explanatory power was considerably lower than that for FIES in Model A (R^2 = 0.536). The contrasting results indicate that adaptive capacity, livelihood resilience, and coping strategies were more strongly associated with households' experienced food-access constraints than with their recent food-consumption patterns. In particular, CSI was strongly associated with FIES but showed virtually no direct association with FCS. These findings further demonstrate that FIES and FCS capture distinct dimensions of household food security and should not be interpreted as interchangeable measures.

3.6 Mediation Analysis

The mediation analysis revealed distinct indirect pathways linking adaptive capacity (ADAPT) to household food insecurity as measured by FIES and FCS (Table 17).

Table 17. Indirect and Total Effects of ADAPT on FIES (Model A, N = 248)

Model / Effect	Indirect pathway	B	SE	95% CI	β	z	*p*	Result
Model A: FIES								
Indirect via LRI	ADAPT → LRI → FIES	−0.035	0.008	[−0.051, −0.019]	−0.224	−4.222	<0.001	Significant
Indirect via CSI	ADAPT → CSI → FIES	−0.023	0.008	[−0.040, −0.009]	−0.148	−2.977	0.003	Significant
Serial indirect	ADAPT → LRI → CSI → FIES	0.002	0.005	[−0.008, 0.013]	0.015	0.447	0.655	Not significant
Total indirect	All indirect pathways → FIES	−0.056	0.01	[−0.076, −0.037]	−0.356	−5.691	<0.001	Significant
Model B: FCS								
Indirect via LRI	ADAPT → LRI → FCS	−0.211	—	—	−0.348	—	<0.001	Significant
Indirect via CSI	ADAPT → CSI → FCS	0.006	—	—	0.011	—	>0.05	Not significant
Serial indirect	ADAPT → LRI → CSI → FCS	−0.001	—	—	−0.001	—	>0.05	Not significant
Total indirect	All indirect pathways → FCS	−0.206	—	—	−0.339	—	—	—

Notes: B = unstandardized effect; SE = standard error; CI = bootstrap 95% confidence interval; β = standardized effect. ADAPT = Adaptive Capacity Index; LRI = Livelihood Resilience Index; CSI = Coping Strategies Index; FIES = Food Insecurity Experience Scale; FCS = Food Consumption Score. Indirect effects were evaluated using 5,000 bootstrap resamples. Statistical significance should primarily be determined from the bootstrap 95% CI.

In the FIES model, two indirect effects were statistically significant. First, ADAPT was indirectly associated with lower FIES through LRI ($\beta = -0.224$, $p < 0.001$), indicating that greater adaptive capacity was linked to greater livelihood resilience, which in turn was associated with lower experienced food insecurity. Second, the indirect pathway through CSI was also significant ($\beta = -0.148$, $p = 0.003$). Because ADAPT was negatively associated with CSI and CSI was positively associated with FIES, greater adaptive capacity was indirectly associated with lower food insecurity through reduced reliance on coping strategies. The combined indirect effect was consequently substantial and significant ($\beta = -0.356$, $p < 0.001$).

In contrast, the hypothesized serial pathway ADAPT → LRI → CSI → FIES was not significant ($\beta = 0.015$, $p = 0.655$). This result aligns with the non-significant LRI → CSI structural path and indicates that livelihood resilience and coping strategies did not operate as a sequential mediator. The FCS model showed a different mediation pattern. The indirect association through LRI was negative, reflecting the negative conditional relationship between LRI and FCS, whereas pathways involving CSI were not supported. Thus, the mediation results did not indicate a common mechanism across the two food-security outcomes. Overall, adaptive capacity was linked to experienced food insecurity through two distinct indirect pathways—livelihood resilience and coping strategies—whereas the

mechanisms underlying recent food-consumption patterns were considerably less consistent. These findings reinforce the distinction between FIES and FCS as complementary measures capturing different dimensions of household food security.

3.7 Comparative explanatory performance of the two models

A comparison of Model A and Model B reveals distinct patterns in how they explain the two dimensions of household food security. The distinct pattern of two models showed in Tabel 18.

Table 18 Comparison of the Explanatory Performance of the FIES and FCS Models

Comparative Indicators	Model A: FIES	Model B: FCS
R^2 outcome	**0,536**	**0,071**
ADAPT → outcome (β)	**−0,275***	0,242 ns
LRI → outcome (β)	**−0,275***	**−0,427***
CSI → outcome (β)	**0,365***	−0,026 ns
Mediation via LRI	Significant*	Significant*
Mediation via CSI	Significant	Not significant
Serial mediation LRI → CSI	Not significant	Not significant
The primary dimensions represented	Experience of limited access to food	Patterns/frequency and diversity of food consumption

Note: β = standardized coefficient; R^2 = coefficient of determination; **p < 0.001; ns = not significant. [a]The direction of mediation via LRI in Model B is negative and requires cautious interpretation because the conditional relationship LRI → FCS is also negative.

Model A, with FIES as the outcome, explains 53.6% of the variation in food insecurity experiences (R^2 = 0.536), whereas Model B, with FCS as the outcome, explains only 7.1% of the variation in food consumption patterns (R^2 = 0.071). These R^2 values represent the proportion of outcome variation explained by the predictors in each model, not overall model fit.

Differences are also evident in the structural path coefficients. In Model A, ADAPT (β = −0.275), LRI (β = −0.275), and CSI (β = 0.365) are all significantly associated with FIES. Conversely, in Model B, only LRI is significantly associated with FCS (β = −0.427), while ADAPT → FCS (β = 0.242) and CSI → FCS (β = −0.026) are not significant. Thus, variation in FIES captures experiences of limited food access more closely than variation in food consumption scores, and is more closely linked to adaptive capacity, livelihood resilience, and the use of coping strategies. These differences also appear in the mediation mechanisms. Model A exhibits two significant indirect pathways—via LRI (β = −0.224) and CSI (β = −0.148)—whereas the serial pathway ADAPT → LRI → CSI → FIES is not supported. In Model B, the mediation pattern is more limited and primarily runs through LRI.

However, differences in R^2 values do not imply that FIES is universally a superior indicator of food security to FCS. The two indicators capture different dimensions: FIES reflects limited access to food, while FCS describes the frequency and diversity of food consumption within a reference period. Therefore, the distinct explanatory power of the two models actually demonstrates the complementary value of both indicators in identifying different aspects of household food security. Figure 6 shows the final structural equation model diagrams for the two models that were analyzed.

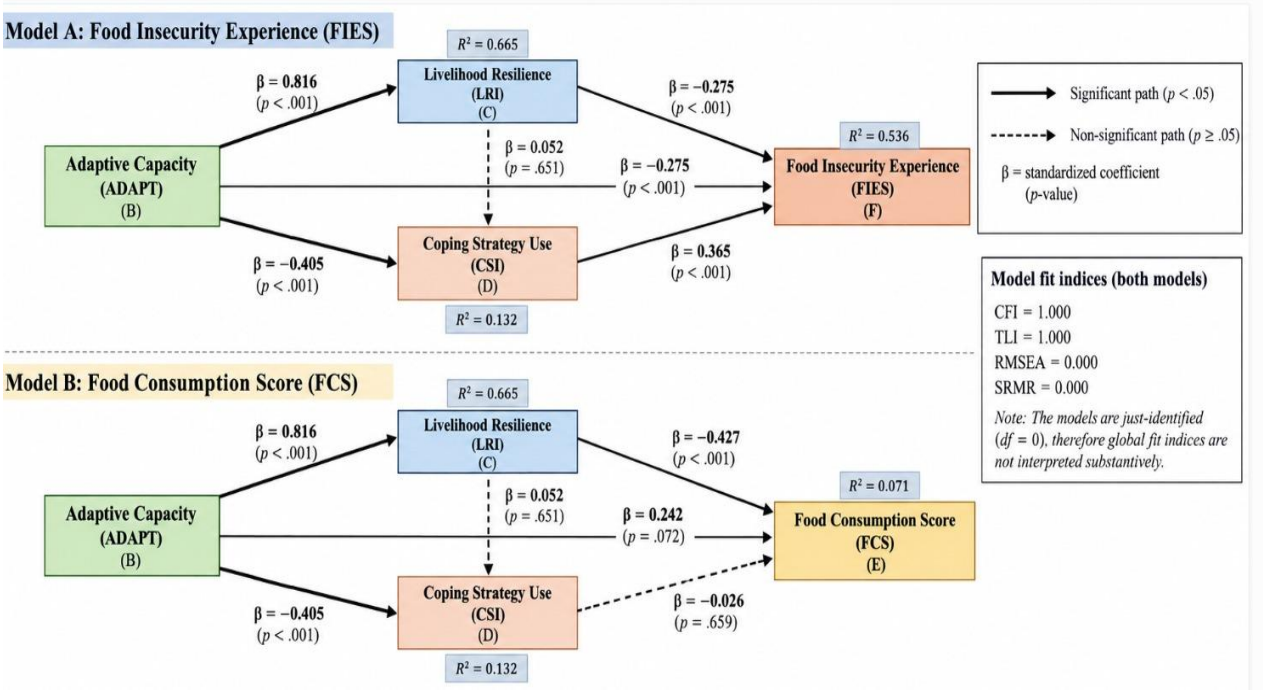

Figure 6 The Final Structural Equation Model Diagrams for The Two Models (Model A and B)

4. DICUSSION

4.1 Climate Adaptation as A Foundation of Livelihood Resilience

The results indicate that adaptive capacity (ADAPT) is strongly and positively related to livelihood resilience (LRI) ($\beta = 0.816$; $p < 0.001$), explaining approximately 66.5% of the variation in LRI ($R^2 = 0.665$). These findings show that seaweed farming households' ability to adapt to environmental stressors and change is a crucial foundation for maintaining livelihood sustainability. Within the framework of livelihood resilience, adaptive capacity is the ability to adjust, leverage resources and opportunities, and implement changes as socio-ecological conditions shift. (Speranza et al., 2014).

These findings are highly relevant for coastal households dependent on seaweed, as their livelihoods face both production and market risks. (Valderrama et al., 2013). Study of (Rimmer et al., 2021) ndicates that seaweed farming in Indonesia yields economic and social benefits and contributes to human and social capital; however, its sustainability remains affected by production instability, product quality, and price fluctuations. Consequently, value chain diversification and technical support are crucial to strengthening farming households' resilience.

Evidence from Indonesian coastal communities also supports this connection. Studies (Martuti et al., 2026; Toiba et al., 2024) indicate that climate change adaptation is positively associated with food security among small-scale fishing and shrimp-farming households, while access to groups, credit, information, and productive resources influences the capacity to adapt. Thus, the strong ADAPT–LRI relationship observed in this study demonstrates that resilience is not merely the ability to withstand shocks but is closely linked to a household's capacity to anticipate, adjust, and reorganize its livelihood strategies. However, given the cross-sectional nature of this study, this

relationship should be understood as a strong structural association rather than causal evidence that an increase in ADAPT directly leads to an increase in LRI.

4.2 Why Livelihood Resilience and Coping Strategies Represent Different Pathways

The results indicate that LRI is not significantly associated with CSI after accounting for ADAPT in the model ($\beta = 0.052$; $p = 0.652$), even though the initial bivariate correlation between LRI and CSI was negative ($r = -0.278$). These findings suggest that livelihood resilience and coping strategies should not be viewed as stages that automatically follow a fixed sequence. The strong ADAPT–LRI relationship ($\beta = 0.816$) also indicates that a household's adaptive capacity explains most of the variation in its ability to cope with change. Once ADAPT is controlled for, LRI does not make a meaningful unique contribution to explaining the use of coping strategies.

Conceptually, livelihood resilience is a broader, long-term capacity that encompasses a household's ability to maintain livelihood functions through buffer capacity, self-organization, and learning (Olazabal; Speranza et al., 2014). In contrast, coping strategies are actual—and generally short-term—responses activated when households face pressure on resources or food access. The literature also indicates that less resilient households tend to activate coping strategies when facing shocks; however, coping remains a response mechanism conceptually distinct from resilience capacity itself (Egamberdiev et al., 2024; Ulimwengu, 2025).

This distinction clarifies why ADAPT has a direct and negative correlation with CSI ($\beta = -0.405$; $p < 0.001$), whereas LRI does not exhibit such a relationship. Adaptive capacity is arguably more closely associated with a household's ability to modify its practices prior to or during the onset of stress, thereby decreasing dependence on more reactive coping mechanisms. Conversely, a relatively high level of resilience does not necessarily imply that a household refrains from employing coping strategies; some strategies might indeed be integral to efforts aimed at sustaining livelihoods amidst periods of stress. Consequently, the findings of this study support the conceptual differentiation among adaptive capacity, livelihood resilience, and coping responses, while also elucidating why the serial pathway ADAPT → LRI → CSI was not empirically validated.

4.3 When Acceptable Food Consumption Coexists with Food-Access Insecurity

One key finding is the discrepancy between food consumption conditions indicated by the FCS and the food-access insecurity experience captured by the FIES. Of the 248 households with complete data, 239 (96.4%) fell into the "acceptable" category based on the FCS. However, among those 239 households, 168 (70.3%) were still classified as experiencing moderate to severe food insecurity. This pattern demonstrates that food consumption appearing relatively adequate during the observation period does not necessarily mean households are free from difficulties in obtaining food.

This difference can be understood by examining the characteristics of the two indicators. The FCS is a composite measure based on food group diversity, consumption frequency over seven days, and the relative nutritional weighting of food groups. Consequently, the FCS primarily reflects household food consumption patterns within a relatively short reference period. The WFP also notes that the FCS aggregation and weighting structure can mask some variations in the actual diversity of food consumed (WFP, 2025). In contrast, the FIES measures experiences of difficulty accessing food because of a lack of money or other resources—ranging from anxiety about food adequacy

to reducing food quantities and experiencing hunger (Cafiero et al., 2018). Thus, households may maintain certain consumption patterns while still facing economic pressure and uncertainty in securing food (Kneafsey et al., 2013).

The CSI results provide additional context for this paradox. The average CSI score was 15.96, with the most frequently reported strategies being reducing food quantities (80.88%), reducing meal frequency (76.89%), and obtaining food on credit (69.72%). Furthermore, CSI shows a moderately strong correlation with FIES ($r = 0.541$) but virtually no correlation with FCS ($r = 0.005$). A similar pattern emerges in the structural model: CSI is positively associated with FIES ($\beta = 0.365$; $p < 0.001$) but shows no significant association with FCS ($\beta = -0.026$; $p = 0.659$). These findings indicate that food-related stress, as reflected in coping strategy use, is more closely linked to limited food access than to variation in the seven-day food consumption score. Substantively, this may reflect households that maintain seemingly acceptable food consumption levels even while facing resource constraints and making various adjustments. The literature suggests that coping strategies are part of household responses to shocks and food-related stress; however, the relationships among coping, resilience, and food security outcomes can be complex and depend on the specific indicators used (Egamberdiev et al., 2024).

Nevertheless, the results do not show that using coping strategies causes FCS to remain in the "acceptable" category. The cross-sectional design precludes establishing a temporal sequence between food access stress, coping strategy use, and observed consumption. Therefore, a more accurate interpretation is that relatively adequate consumption and food access stress can coexist. These findings underscore the importance of using FCS and FIES complementarily: FCS provides information on actual consumption patterns, whereas FIES reveals experiences of limited access that observed consumption alone may not fully capture.

4.4 The Contrasting FIES and FCS Results

The results reveal a clear distinction between models using FIES and FCS as food security outcomes. In Model A, ADAPT ($\beta = -0.275$), LRI ($\beta = -0.275$), and CSI ($\beta = 0.365$) were all significantly associated with FIES, and the model explained 53.6% of the variation in FIES. Conversely, in Model B, only LRI was significantly associated with FCS ($\beta = -0.427$), while ADAPT and CSI were not, and the model explained only 7.1% of the variation in FCS. This difference can be attributed, first, to the distinct concepts being measured. FIES specifically captures the experience of limited food access due to a lack of money or resources (Grimaccia & Naccarato, 2019), whereas FCS is a composite indicator based on the frequency, diversity, and relative nutritional weight of food groups consumed over a seven-day period (Cafiero et al., 2018)(WFP, 2026).

A second explanation, directly supported by the study data, is the low categorical variation in FCS scores. Of 248 households, 239 (96.4%) were classified as having "acceptable" consumption. This concentration in a single category suggests that food consumption was relatively homogeneous under the FCS classification, whereas experiences of food access—as measured by FIES—showed much greater variation. The FCS aggregates consumption frequency across eight food groups over seven days using specific weights and allows classification based on standard cut-offs (WFP, 2026). This may limit the FCS's ability to differentiate economic vulnerability among households when most households consistently consume the same food groups.

A third explanation relates to the consumption characteristics of coastal communities, though this study should treat it as a tentative hypothesis. Studies on Indonesian coastal communities indicate that fish can be obtained for direct consumption or through income generated from fishing activities; consequently, the availability of protein-rich food does not necessarily reflect a household's broader economic capacity to secure food. Research (Viana et al., 2023) highlights the heavy reliance of populations in tropical regions and developing countries on this sector. In many coastal communities, diets rely primarily on carbohydrates (such as rice, wheat, and cassava), with seafood as the sole source of animal protein. This aligns with the study's findings, which show that the "fish/meat/eggs" food group accounts for the second-largest proportion of the diet, following staple foods. At the same time, unstable fishing income and limited market access can still lead to food insecurity (Gibson et al., 2020; Roberts et al., 2023). A similar pattern has been observed among fishing households in Komodo, where access to certain nutritious foods coexists with high levels of food insecurity (Gibson et al., 2021). However, this study did not directly test whether access to fish or local foods drives high FCS scores; thus, further research is needed to clarify this relationship.

Finally, the FCS's aggregation may mask variation in consumption quality within food groups. The standard FCS is not designed to measure individual intake or overall micronutrient adequacy; the WFP developed the FCS-N specifically to capture data on the consumption of foods rich in vitamin A, protein, and heme iron (WFP, 2026). Therefore, a low R^2 value for the FCS does not imply that it is a universally weaker indicator. Instead, the results suggest that ADAPT, LRI, and CSI are more closely associated with the food access dimension the FIES captures than with the short-term consumption patterns the FCS reflects. Therefore, the two indicators provide different yet complementary information about coastal households' food security.

4.5 Theoretical Contributions

This study makes several theoretical contributions to the literature on climate change adaptation, livelihood resilience, coping strategies, and coastal household food security. First, it reinforces the view that adaptive capacity and livelihood resilience are closely related yet distinct concepts. The strong ADAPT–LRI relationship ($\beta = 0.816$; $p < 0.001$) indicates that a household's ability to adjust to change is a crucial component in building livelihood resilience. This aligns with the framework proposed by (Speranza et al., 2014), which positions adaptive capacity as a vital element of a livelihood system's ability to cope with socio-ecological changes. However, the lack of significance in the LRI → CSI pathway once ADAPT is accounted for suggests that resilience does not automatically translate into a reduced reliance on coping strategies.

Second, this study clarifies the theoretical distinctions between adaptation, resilience, and coping. Adaptation and resilience represent relatively broader capacities to anticipate, adjust to, and maintain livelihood functions, whereas coping more directly reflects household responses to stressors that are currently unfolding or have already occurred. This distinction matters because the literature often uses these three concepts interchangeably, even though they describe different processes and time horizons (Béné et al., 2016).

Third, the study's primary contribution is integrating two dimensions of food security into a single structural framework. The divergent results between FIES and FCS show that relationships among adaptation, resilience, coping, and food security depend on the specific outcome dimension observed. Collectively, ADAPT, LRI, and CSI explain

53.6% of the variation in FIES but only 7.1% in FCS. These findings support the view that food security is a multidimensional construct, meaning that different indicators are not necessarily interchangeable (Cafiero et al., 2018; Jones et al., 2013).

Fourth, this study argues that seemingly adequate food consumption is not always synonymous with secure food access. The coexistence of an "acceptable" FCS score with experiences of food insecurity (as measured by FIES) reveals a potential gap between observed food consumption and experienced food access. Thus, this study's theoretical contribution lies not in positioning FIES as superior to FCS, but in showing that household food security resilience must be understood through a combination of adaptive capacity, responses to stress, food access, and actual consumption. This perspective expands the livelihood resilience framework—moving beyond the mere ability to maintain a livelihood—toward a more multidimensional understanding of how coastal households cope with food-related stressors.

Fifth, the study's findings offer a new framework for livelihood resilience among coastal communities—specifically seaweed farmers—by integrating adaptive capacity and coping strategies. While some studies have attempted to link these variables—for instance, (Nuryadi & Muthalib, 2026) explain that affected households employ economic adjustment strategies, livelihood diversification into fisheries and informal trade, and social adjustment mechanisms rooted in kinship and community support—socio-economic vulnerability arises from the interplay of declining natural capital, limited livelihood alternatives, low education levels, and financial uncertainty. That study advocates for integrated coastal zone management policies in response to mining activities in Southeast Sulawesi, Indonesia. Similarly, (Makame et al., 2023) examine the responses of farmers, fishers, and seaweed farmers to various shocks and stressors; their research also investigates responses that were discontinued for various reasons, as well as the adaptation barriers faced by these communities and the implications for coastal populations. However, no study has yet comprehensively integrated the variables of adaptive capacity, livelihood resilience, CSI, FCS, and FIES using SEM analysis.

4.6 Policy Implications

This study's findings have significant implications for policy formulation on food security and the livelihoods of coastal communities, particularly households dependent on seaweed farming. First, the strong relationship between adaptive capacity and livelihood resilience ($\beta = 0.816$) indicates that policies should not focus only on post-shock recovery but also on strengthening households' capacity to anticipate and adapt livelihoods to climate change. Interventions could improve access to climate information, adaptation knowledge and skills, cultivation technologies suited to environmental conditions, finance, farmer organizations, and the ability to respond to production and market fluctuations. This approach aligns with the FAO framework, which links climate change adaptation to strengthening livelihood resilience and market access in small-scale fisheries communities.

Second, policies must address livelihood stability and food access simultaneously. The study results show that adaptive capacity and livelihood resilience are negatively correlated with FIES, whereas coping intensity is positively correlated with FIES. This pattern indicates that increasing seaweed production alone cannot adequately address food insecurity in coastal households. Livelihood strengthening programs need to include income-source diversification, more stable market access, stronger group economic institutions, affordable savings or financing

options, and social protection schemes that can be used during periods of declining production or income. These strategies matter because the FAO positions livelihood resilience, market access, climate adaptation, and food security as interconnected components in developing small-scale fisheries communities.

Third, the study results underscore the need for a food security monitoring system that utilizes multiple indicators. While 96.4% of households had an "acceptable" Food Consumption Score (FCS), 70.3% fell into the moderate or severe categories of the Food Insecurity Experience Scale (FIES). This distinction matters for policymaking because the FCS reflects the diversity, frequency, and relative nutritional value of food groups consumed over a seven-day period, whereas the FIES directly captures the difficulty of accessing food due to resource constraints.

Consequently, an "acceptable" FCS should not be used in isolation to conclude that a household is food secure. The FAO emphasizes that no single instrument can capture all dimensions of food security and advocates using the FIES alongside other indicators for a more comprehensive understanding. For seaweed-farming households, monitoring that combines indicators of consumption, food access experiences, and coping strategies can identify vulnerabilities hidden beneath seemingly adequate consumption patterns. The key policy implication is that program success should be measured not only by a household's ability to maintain consumption levels but also by reductions in food access difficulties and reliance on coping strategies that signal economic stress.

5. CONCLUSION

This study demonstrates that climate adaptive capacity, livelihood resilience, coping strategies, and household food security are closely interconnected, but their relationships depend substantially on how food security is measured. First, adaptive capacity was strongly and positively associated with livelihood resilience, indicating that households with greater capacity to anticipate and adjust to environmental and livelihood pressures also tended to exhibit stronger livelihood resilience. This finding highlights adaptive capacity as a key foundation for strengthening coastal seaweed-farming households' ability to withstand and respond to changing conditions.

Second, the structural models revealed markedly different relationships when food security was represented by the Food Insecurity Experience Scale (FIES) and the Food Consumption Score (FCS). Adaptive capacity, livelihood resilience, and coping strategies were significantly associated with FIES, and the model explained 53.6% of its variance. In contrast, the FCS model explained only 7.1% of the outcome variance, with livelihood resilience emerging as the only significant direct predictor of FCS. The FIES model also identified significant indirect pathways through livelihood resilience and coping strategies individually, whereas the serial pathway through livelihood resilience and coping was not supported.

Most importantly, acceptable food consumption did not necessarily imply secure food access. A substantial proportion of households classified as having acceptable FCS simultaneously reported moderate or severe food-access constraints based on descriptive FIES categories. These findings emphasize that household food security among seaweed-farming communities is multidimensional, not captured by **a single indicator**. Combining consumption-based measures with experience-based food-access indicators and information on coping responses can provide a more

comprehensive assessment of household vulnerability and resilience. Policies should therefore simultaneously strengthen adaptive capacity, stabilize livelihoods, and reduce persistent constraints on household food access.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval

This research was conducted in accordance with the ethics committee guidelines and approved by the International Review Board (IRB) of Sultan Ageng Tirtyasa University with registration number No. 49/IRC/EC/LPPM/2026. All respondents who participated in this study were adults (17 years and above) and informed consent has been obtained from the subjects who were respondents in this study.

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