Adaptation Mechanisms and Livelihood Resilience of Small-Scale Fishermen to Climate Variability in Central Tapanuli, North Sumatra

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Abstract—Climate variability increases the vulnerability of small-scale fishing communities, particularly in coastal areas that rely heavily on fishery resources as their primary source of livelihood. This study aims to identify fishermen's adaptation mechanisms, analyze the level of livelihood resilience, and determine the factors influencing the resilience of small-scale fishermen in two coastal villages in Central Tapanuli Regency, namely Teluk Roban Village and Pasar Sorkam Village. This study employs a mixed-methods approach, collecting quantitative data through a survey of 70 small-scale fishing households, as well as qualitative data through in-depth interviews with informants selected based on the principle of data saturation. The research findings indicate that fishing households in both villages employ various adaptation strategies to mitigate the impacts of climate variability on their income sources. These strategies can be categorized into economic, ecological, and social adaptation mechanisms. In general, the resilience of fishing households falls into the moderate category, reflecting their high dependence on the fisheries sector and limited livelihood capital. Resilience among fishermen in Teluk Roban Village is influenced by educational level, access to financial institutions, livestock ownership, and the size of the fishing fleet. Meanwhile, in Pasar Sorkam Village, resilience is influenced by the head of household's age, non-fishing income, and access to natural capital such as mangroves, rice fields, and plantation crops. Although they have different livelihood characteristics, the resilience levels of fishermen in both villages do not show significant differences and generally fall into the moderate category. These findings underscore the importance of livelihood diversification, access to financial resources, and the utilization of natural resources in strengthening fishermen's adaptive capacity to climate variability.

Keywords—.Economic adaptation mechanisms, ecological adaptation mechanisms, fishermen's resilience levels, factors influencing fishermen's resilience, social adaptation mechanisms.

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I. INTRODUCTION

Climate variability causes fluctuations and instability in weather patterns and rainfall, creating shifting weather cycles [1][2][3]. Climate variability also causes sea levels to rise and the intensity of tidal flooding to increase [4][5].

Climate variability not only affects ecology, but also the communities that live within it. The most vulnerable category of society is fishermen, because their livelihoods are highly dependent on natural conditions [6][7]. Fishermen are a relatively fragile group of people. Degradation of the fishery resource ecosystem, which is the basis of fishing activities, can have a direct impact on the stability of their livelihoods [8][9]. Moreover, the majority of fishermen in Indonesia are traditional fishermen with low incomes and minimal socioeconomic capabilities [10][11][12][13][14][15]. The greatest impact of this ecological damage is the fish shortage season [16]. The shortage season for fishermen results in changes in the catch, both in terms of quantity and type of fish. This disrupts the stability of fishermen's livelihoods [17][18][19].

Based on the findings of the presentation on the conditions of fishing communities and the occurrence of climate variability, there is a need for a specific study on how to adapt to climate variability so that fishermen (especially small-scale fishermen) become resilient. Fishermen are said to be resilient if they are able to respond to changes and pressures in a positive manner and maintain their core functions within the community even when under pressure [20].

II. METHOD

A. Place and Time

This study was developed using data obtained from fishing communities in Pasar Sorkam Village and Teluk Roban Village, Central Tapanuli Regency, North Sumatra Province. The study was conducted from July to August 2024. These villages were selected purposively because they represent the areas most affected by climate variability in the province. In addition, both villages are

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inhabited by small-scale fishing households that rely on the fisheries sector as their main livelihood.

B. Data and Data Sources

The data used in this study is primary data. Primary data in this study was obtained through questionnaires and interviews with respondents and informants.

Respondents were selected using purposive sampling. The sample criteria were small-scale fishermen using boats under 10 GT. Small-scale fishing households are fishermen who catch fish using boats under 10 GT [21]. A total of 70 fishing households were involved as respondents, consisting of 35 fishing households from Pasar Sorkam Village and 35 fishing households from Teluk Roban Village.

Informants in this study were selected using purposive sampling, which involves deliberately selecting informants who clearly understand all the characteristics and lives of fishermen, such as fishermen, fishermen group leaders, community leaders, the Pasar Sorkam Village Administration, and the Teluk Roban Village Administration. The number of informants was based on data saturation.

C. Data Analysis

The data obtained in the study were analyzed using two approaches, namely quantitative and qualitative. Quantitative data were analyzed using SPSS version 20. Meanwhile, qualitative data were analyzed using qualitative data analysis, namely data reduction, data presentation, and conclusion drawing [22].

Livelihood resilience can be measured by the speed of recovery of fishermen after experiencing a crisis or the adverse effects of climate variability [23][24][25]. Livelihood resilience is equal to the number of adaptation mechanisms that fishing households can use to return to normal after a crisis [26]. Livelihood adaptation mechanisms are active strategies used by rural households to survive in response to climate or environmental change [27]. Adaptation mechanisms are divided into three different levels of resilience. If fishermen only have one to three adaptation mechanism options, this is considered a low level of livelihood resilience. If a fisher has four to seven adaptation mechanism options, this is considered a medium livelihood resilience level. If a fisher has eight to ten options for survival or adaptation mechanisms, this is referred to as a high livelihood resilience level. In other words, the more options for survival resilience a person has, the greater their resilience in facing crises, and vice versa.

Multiple linear regression was used to identify factors affecting livelihood resilience. Factors affecting the livelihood resilience of fishing households are described by the following model:

$$LR = f(X_1, X_2, X_3 \ X_4, X_5, \ldots X_{12})$$

(1)

The dependent variable LR is the speed of recovery from crisis and represents the livelihood resilience of fishing households. LR_{mn} or livelihood resilience is intended for fishing households in Muara Nibung

Village, LR_{ps} intended for fishing households in Pasar Sorkam Village, and LR_{tl} intended for fishing households in Teluk Roban Village.

The level of livelihood resilience is influenced by several factors, namely the age of the head of the fisher household (X1), the education level of the fisher household (X2), non-fishery income that supports the fisher household's survival (X3), the number of fishing vessels owned (X4), total economic value of livestock owned by fishermen (X5), livestock ownership (X6), access to financial institutions (cooperatives/banks) (X7), access to natural capital (mangroves, rice fields, mango and coconut trees) (X8), quality of human capital (technical skills of human resources) (X9), financial capital owned by fishermen to support their livelihoods (X10) , and the scale of social capital in the form of social networks and organizations to support fishermen's livelihoods (X11), additional fishing gear (X12).

III. RESULTS AND DISCUSSION

A. Adaptation Mechanisms and Resilience Levels Small-Scale Fishing Households

The impact of climate variability is a source of disruption for fishing households [28][29]. Although not all fishermen in both villages experience the same level of crisis, they generally develop similar adaptations to survive. Fishing households develop adaptation mechanisms to minimize the risks associated with the damaging effects of climate variability. These strategies can be grouped into three broad categories:

a. Economic adaptation mechanisms, including 1) diversifying sources of income from rice fields, oil palm plantations, mango and coconut trees, local chicken and buffalo farming; 2) utilizing savings; 3) accessing and utilizing government assistance such as the Family Hope Program (PKH), Direct Cash Assistance (BLT) and Non-Cash Food Assistance (BPNT); 4) accessing lending institutions such as savings and loan cooperatives and banks for financial support; 5) activities to increase the economic value of catches through the process of salting fish (ikan asin); 6) opening small businesses (grocery stores, food stalls).

b. Ecological adaptation mechanisms, including 1) utilization of mangrove forests; 2) use of additional environmentally friendly fishing gear, such as pacing and rawai.

c. Social adaptation mechanisms, including 1) utilizing local social ties to support livelihoods (cash and food assistance in times of need); 2) joining fishermen's groups to strengthen their voice in communicating their needs and interests to the government or other institutions.

Fishery households in both villages utilize various adaptation mechanisms to mitigate the adverse impacts of climate variability that could threaten their primary source of income. The adaptation strategies implemented are generally contextual and tailored to the severity of the risks faced. When the impacts are temporary or relatively minor, such as sudden rainfall that prevents fishermen from going out to sea, fishing households in

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Teluk Roban Village tend to implement economic adjustment strategies by utilizing savings or available sources of income to meet their daily needs. This economic asset-based adaptation strategy is a form of buffer strategy commonly used by small-scale fishing households in response to short-term disruptions to fishing activities.

Under the same conditions, most fishing households in Pasar Sorkam Village not only rely on economic adaptation mechanisms but also utilize their social capital. Relatively strong social relationships among community members enable fishermen to help each other through informal mechanisms such as inter-relative loans, information sharing, or economic cooperation. International research shows that social capital plays an important role in increasing the adaptive capacity of coastal communities to environmental change. Other studies show that social networks, community trust, and collective cooperation are important factors that help fishing communities reduce their vulnerability to climate change and fluctuations in fishery resources [30].

| start a small food stall business | buffalo farming | clearing land for oil palm cultivation |

Figure 1. Economic adaptation mechanisms implemented by fishermen in Teluk Roban Village

| planting mango trees in the yard | planting coconut trees | fisherman's wife cuts fish to make salted fish |

clearing land for rice fields
Figure 2. Economic adaptation mechanisms implemented by fishermen in Pasar Sorkam Village

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When fishing households face greater climate variability impacts, such as prolonged fish shortages, fishermen in both villages show relatively similar adaptive response patterns, namely by utilizing alternative livelihoods outside of fishing activities. However, fishing households in Pasar Sorkam Village have more diverse adaptation strategies than fishermen in Teluk Roban Village. Teluk Roban fishermen generally rely solely on the produce from their rice fields as a source of additional income. In contrast, fishermen in Pasar Sorkam Village have a more diverse combination of assets, such as rice fields, mango trees, and coconut trees, the produce of which can be sold for cash when fish catches decline.
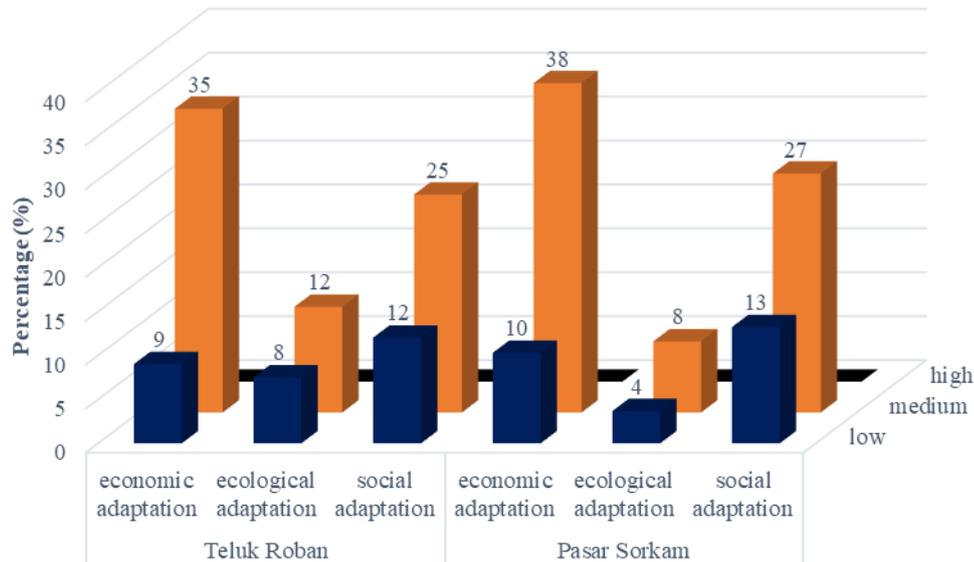

Figure 3. Mechanisms for adapting the livelihoods of small-scale fishing households during times of crisis

These findings indicate that diversifying livelihoods is an important adaptation strategy for fishing households in the face of environmental uncertainty. Another study of coastal fishing communities in Bangladesh shows that fishing households with alternative sources of income outside the fisheries sector tend to have a higher capacity to adapt to climate change and fluctuations in fishery production [31]. Other studies also show that diversifying livelihood assets such as agricultural land ownership, plantation crops, or non-fisheries businesses can increase the economic stability of fishing households and reduce their dependence on marine resources [32][33].

Overall, the results of this study show that the adaptation strategies of fishing households do not only depend on fishing activities alone, but are also influenced by the diversity of livelihood assets and the strength of social networks in coastal communities. Therefore, efforts to increase the resilience of fishing households need to be directed at strengthening livelihood diversification, increasing access to alternative economic resources, and strengthening the social institutions of coastal communities as part of adaptation strategies to climate change.

Based on the results of the study in Figure 4, the distribution of the resilience levels of fishing households in Teluk Roban Village and Pasar Sorkam Village are classified into three categories, namely low, medium, and high. The results of the analysis show that most fishing households in both villages are in the medium resilience category. In Teluk Roban Village, 57% of fishing households are in the medium resilience category and 43% are in the low category, while no fishing households are in the high resilience category. A similar pattern was also found in Pasar Sorkam Village, where 60% of fishing households were in the medium resilience category and 40% were in the low category, and no fishing households were found to have a high level of resilience.

The distribution shows that most fishing households in both villages have sufficient adaptive capacity but are not yet strong enough to cope with the pressures of climate variability. The moderate resilience rating indicates that fishermen still have the ability to withstand various shocks, but this capacity is not yet strong enough to achieve a high level of livelihood resilience.

This finding is in line with various international studies showing that small-scale fishing communities generally have moderate levels of resilience due to their high dependence on fishery resources and limited access to livelihood capital. A study of small-scale fishermen in Ghana shows that the livelihood resilience of fishermen is influenced by various socio-economic factors such as education, seafaring experience, economic status, and involvement in fishermen's organizations, which determine their ability to adapt to changes in fishery resources and economic pressures [34].

In addition, other studies on the livelihood resilience of fishermen show that the resilience of fishing households is the result of interactions between buffer capacity, learning capacity, and self-organization

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capacity in facing social and ecological changes in coastal areas [35].

In the context of small-scale fisheries, high dependence on the fisheries sector makes fishing households very vulnerable to environmental and economic changes. Many coastal fishing communities depend almost entirely on fishing activities as their main source of income, so fluctuations in catch or disruptions to fisheries policy can directly affect the stability of their livelihoods [36].

In addition to ecological factors, resilience is also greatly influenced by the socio-economic conditions of coastal communities. Research on the adaptive capacity of fishing communities shows that factors such as education levels, access to markets, and the isolation of coastal areas can affect the ability of communities to respond to environmental changes and economic pressures [37].
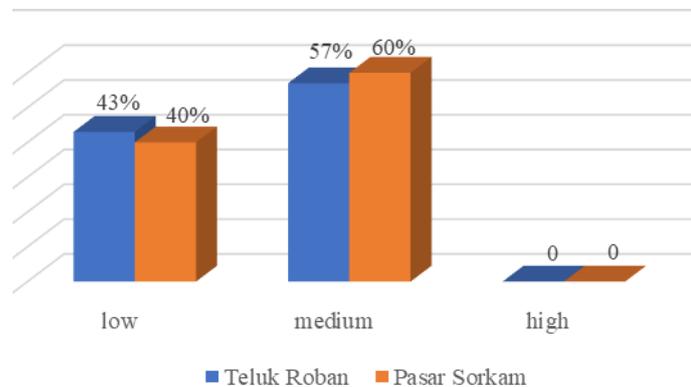

Figure 4. The level of resilience among fishing households in the two villages

Thus, the dominance of the resilience category in this study shows that fishing households in both villages are still in a state of relatively limited livelihood resilience, where they are able to withstand certain pressures but still have a high level of vulnerability to various shocks resulting from the impacts of climate variability.

TABLE 1
FACTORS INFLUENCING LIVELIHOOD RESILIENCE IN THE TWO STUDY VILLAGES

Variable	Teluk Roban						Pasar Sorkam					
	Un-standardized Coeff.		Stdzd Coeff.	T	Sig.	VIF	Un-standardized Coeff.		Stdzd Coeff.	T	Sig.	VIF
	B	Std. Error	Beta				B	Std. Error	Beta			
Constant	0.238	0.276	0.189	0.864	0.397	1.576	0.780	0.284		2.744	0.012	1.394
X1	0.335	0.280	0.578	1.195	0.244	1.279	-0.069	0.262	-0.052	-0.265	0.793	1.728
X2	0.655	0.162	0.166	4.053	0.000	15.244	0.247	0.187	0.286	1.323	0.199	15.675
X3	0.165	0.488	0.609	0.337	0.739	3.763	-1.205	0.492	-1.598	-2.451	0.023	3.065
X4	0.861	0.346	-0.236	2.489	0.020	1.561	-0.168	0.234	-0.207	-0.719	0.480	2.978
X5	-0.252	0.168	-0.476	-1.500	0.147	2.175	0.345	0.215	0.456	1.606	0.122	2.223
X6	-0.561	0.219	-0.692	-2.558	0.018	3.755	0.232	0.246	0.232	0.947	0.354	1.703
X7	-1.223	0.432	-0.187	-2.829	0.010	1.552	-0.249	0.164	-0.326	-1.518	0.143	12.909
X8	-0.189	0.159	0.178	-1.191	0.246	13.281	0.966	0.448	1.277	2.159	0.042	3.217
X9	0.176	0.455	0.040	0.387	0.702	2.061	-0.041	0.255	-0.048	-0.162	0.873	1.351
X10	0.044	0.198	0.076	0.221	0.827	2.201	0.022	0.145	0.029	0.150	0.882	2.622
X11	0.076	0.186	0.189	0.406	0.688	1.576	0.111	0.239	0.124	0.464	0.647	1.631
X12	0.238	0.276	0.578	0.864	0.397	1.279	0.262	0.164	0.336	1.599	0.124	1.394

Dependent Variable: Index off Resilience (IR)

Statistic Parameter	Research Village	
	Teluk Roban	Pasar Sorkam
R-Square	0.634	0.403
Adjusted R-Square	0.459	0.078
SE Regression	5.433	2.006
Sum of Residual	3.138	2.966
Kolmogorov-Smirnov Z	0.755	1.099
Asymp.Sig. (2 tailed)	0.619	0.179
F-Statistics	3.620	1.240
Durbin Watson	2.668	2.180

B. Factors Affecting the Resilience of Small-Scale Fishing Households

This study uses statistical tests to examine the factors that significantly affect the livelihood resilience of small-scale fishing households. The results show that the livelihood resilience of small-scale fishing households in both study villages is influenced by at least 12 factors, as shown in Table 1.

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The results of the statistical analysis show that the factors that influence the resilience of fishing households in Teluk Roban Village include the level of education of fishing households (X2), access to financial institutions such as cooperatives or banks (X7), ownership of livestock (X6), and the number of fishing fleets owned (X4). These findings indicate that the resilience of fishermen is not only determined by their fishing production capacity, but also by a combination of human capital, financial capital, and physical capital owned by fishing households. The level of education, for example, plays an important role in improving the ability of fishing households to access information, adopt innovative fishing technologies, and develop strategies to adapt to changes in environmental and market conditions. A number of previous studies have also shown that human capital, particularly education, is an important factor in increasing the adaptive capacity of coastal communities to ecological and economic pressures [38][39].

Figure 5. The fishing fleet owned by the fishermen of Teluk Roban Village

Access to financial institutions is also a significant factor in strengthening the resilience of fishing households. Easy access to financing allows fishermen to invest in fishing gear, boat repairs, or business diversification, which can increase household income stability. Other studies show that access to formal financial services is an important component in strengthening the livelihoods of coastal communities, as it enables fishing households to manage economic risks and reduce vulnerability to fluctuations in catch yields [40][41]. In addition, livestock ownership, which was found to be a significant factor in this study, indicates the existence of a household asset diversification strategy as a form of economic buffer mechanism when catches decline. Diversification of non-fishery assets such as livestock has been widely identified as an important strategy in increasing the resilience of coastal communities' livelihoods [42].

On the other hand, the size of the fishing fleet owned by fishermen also contributes to household resilience (Figure 5). Ownership of a more adequate fleet or fishing gear provides fishermen with flexibility in determining fishing locations and times, as well as increasing the chances of obtaining more stable catches. This finding is in line with research showing that physical capital in the capture fisheries sector, such as boats and fishing gear, is closely related to fishermen's ability to maintain their livelihoods [43][44].

Meanwhile, in fishing households in Pasar Sorkam Village, the factors that influence resilience are the age of the head of the family who is still classified as productive age (X1), non-fishery income (X3) and access to natural capital (X8) such as mangrove forests, rice fields, and fruit trees such as mango and coconut. These findings indicate that income diversification strategies are an important element in increasing the resilience of fishing households. Over-reliance on the fisheries sector often increases vulnerability to environmental change, making alternative income outside the fisheries sector an important mechanism for maintaining household economic stability. Other studies show that coastal households with alternative sources of income tend to have a higher capacity to adapt to changes in marine resources [45][46][47].

In addition, access to natural capital such as mangrove ecosystems and agricultural land also contributes significantly to the resilience of coastal communities. Mangrove ecosystems, for example, not only serve as important habitats for fishery resources, but also provide various direct economic benefits to coastal communities, such as sources of timber, food, and protection against abrasion and storms. Other research in Ecological Economics shows that coastal ecosystems such as mangroves have high economic value for local communities and play an important role in enhancing the socio-ecological resilience of coastal communities [48]. Therefore, access to natural capital in this study can be understood as an important factor that strengthens the adaptive capacity of fishing households in facing environmental pressures and climate change.

IV. CONCLUSION

This study shows that small-scale fishing households in Teluk Roban Village and Pasar Sorkam Village have developed various adaptation mechanisms to maintain livelihood stability in the face of climate variability pressures. These adaptations are not only economic in nature, but also include social and ecological dimensions that shape the resilience of coastal communities' livelihoods. Strategies such as income diversification, use of savings, access to social assistance, utilization of coastal resources, and strengthening of local social networks are important elements in maintaining the sustainability of fishermen's livelihoods when fishing activities are disrupted by changes in environmental conditions.

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The findings show that the level of resilience of fishing households in both villages is generally in the moderate resilience category, indicating that most fishermen have sufficient adaptive capacity to respond to short-term disturbances, but do not yet have the strong ability to cope with more complex long-term pressures. This condition shows that the livelihoods of fishermen are still relatively vulnerable, mainly due to their heavy dependence on the capture fisheries sector and limited access to broader economic and institutional resources.

This study also found that the factors affecting the resilience of fishermen's livelihoods are contextual and vary between regions. In Teluk Roban Village, the resilience of fishing households is influenced by a combination of human capital, financial capital, and physical capital, namely education levels, access to financial institutions, livestock ownership, and the size of the fishing fleet. These factors show that fishermen's ability to access information, sources of financing, and production assets plays an important role in increasing their capacity to adapt to environmental and economic changes. Meanwhile, in Pasar Sorkam Village, livelihood resilience is more influenced by the age of the household head, diversification of non-fishing income, and access to natural capital such as mangrove forests, rice fields, and plantation crops. These findings suggest that livelihood diversification and access to alternative natural resources are key factors in maintaining the economic stability of fishing households.

Overall, this study confirms that the livelihood resilience of fishermen is not only determined by fishing activities, but is the result of interactions between various livelihood assets owned by fishing households, including human, financial, social, physical, and natural capital. Therefore, efforts to improve the resilience of coastal communities to climate variability need to be carried out through an integrated approach by strengthening livelihood diversification, improving access to financing sources, and maintaining the sustainability of coastal ecosystems that form the basis of the livelihoods of fishing communities.

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