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Research Article

Sustainability of Small-Scale Capture Fisheries Based on Coastal Vulnerability in Pangpang Bay, Banyuwangi Regency, Indonesia

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Abstract

Teluk Pangpang is one of the water areas that has considerable potential for capturing fisheries in Banyuwangi Regency, Indonesia. On the other hand, climate change impacts the vulnerability of coastal areas and coastal communities, especially small-scale fishers. This study aims to analyse the coastal vulnerability of Pangpang Bay and formulate a sustainable development plan for small-scale capture fisheries in Pangpang Bay. The research method used a descriptive method with a quantitative approach. Data collection techniques used geographic information systems and focus group discussions (FGDs). The data analysis used was Coastal Vulnerability Index (CVI) analysis with a spatial approach and Participatory Prospective Analysis (PPA). From the CVI analysis, through the assessment of geomorphological parameters, erosion/accretion, coastal slope, distance of plants from the beach, wave height, and average tide range, the level of coastal vulnerability of Teluk Pangpang is included in the low category. Meanwhile, the PPA analysis resulted in seven variables that most influence the sustainability of small-scale capture fisheries, namely climate change, coastal vulnerability, coral reef area and density, number of small-scale fishers, catches, human resources of small-scale fishers, and management of small-scale fisheries resources. Furthermore, the formulation of the sustainability scenario of small-scale capture fisheries in Pangpang Bay is to minimise the impact of climate change and conduct disaster mitigation, improve the human resources of small-scale fishers, and equalise perceptions as outlined in the commitment between all interested parties and small-scale fishing communities.

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1. Introduction

"Small-scale fisheries" or "artisanal fisheries" are fisheries that are either semi-commercial or non-commercial fisheries on a small scale (Hanich *et al*., 2018). Climate change impacts have resulted in significant temperature fluctuations in some coastal areas where fishers live. It also has a significant impact on marine resources, decreasing fish stocks and affecting fish migration patterns, incubation periods, and reproduction (Shaffril *et al*., 2017). Sea level rise and increased coastal erosion as a result of climate change, leaving fishermen vulnerable, consequently disrupting the coastal economy and its surroundings (Colburn *et al*., 2016).

Climate change, including those affecting coastal areas, can pose a major threat not only to nature but as well as to people around the world. The impact of climate change on coastal areas is significant, as rising sea levels lead to extreme weather and climate events such as high waves, heavy rains, storms, and floods (Furlan *et al*., 2021). Pacific Island countries (Pacific Island Countries and Territories or PICTs) are already affected by climate change and are expected to continue to be disproportionately impacted by rising temperatures, increased extreme weather events, changing rainfall patterns, sea level rise, coastal erosion, ocean acidification and coral reef bleaching (Hanich *et al*., 2018). The study of risks, hazards, and vulnerabilities in coastal areas is becoming increasingly important due to the increasing pressure on these areas. These pressures are increasing due to population growth, where greenhouse gases are causing severe climate change (Ferreira *et al*., 2021). Climate change has a negative impact on various human needs and activities, including physical impacts on a location, but it also depends on the vulnerability and resilience of the population and infrastructure (Guilyardi *et al*., 2018). Ecological degradation due to climate change leads to increased vulnerability of coastal areas. Therefore, future predictions are needed by measuring coastal vulnerability to sea level rise, storm surges and winds under current climate conditions. The results will inform and inform the prioritisation of conservative and adaptive measures to mitigate the damaging impacts of development, thereby increasing the resilience of coastal communities (Zhang *et al*., 2024).

Large-scale disasters and technological advances in recent decades have resulted in an increasing number of publications on coastal hazards. Vulnerability theory emerged in response to the environmental risks posed by coastal environmental hazards, including storms and coastal erosion, which pose significant physical, economic and social challenges. The term coastal vulnerability itself is a spatial description of people and places vulnerable to coastal hazards. Understanding vulnerability in coastal areas relates to complex systems by determining the spatial distribution of risks and hazards in coastal areas (Bevacqua *et al*., 2018). Coastal vulnerability studies are typically conducted using different methods, focusing on community factors or policy implications. By reviewing the existing literature, there is methodological and policy relevance that aligns with other approaches in vulnerability assessment (Bukvic *et al*., 2020). Coastal vulnerability assessments include using the Coastal Vulnerability Index, which serves as a numerical approach to classify coastal areas based on the influence of relevant parameters (González-Baheza and Arizpe, 2018). The presented method for evaluating coastal vulnerability is the Coastal Vulnerability Index (CVI), in this case, adapted to the specific natural conditions of the study area and provides a valuable contribution to coastal management, particularly due to climate change (Ružić *et al*., 2019).

Achieving sustainable development goals requires not only protecting the environment from ecological vulnerability but also the impacts of climate change threats on human life, health and happiness (human vulnerability). In other words, a city or community is more sustainable if it is less vulnerable (González-Baheza and Arizpe, 2018). Government officials and decision-makers can use coastal vulnerability assessments to evaluate factors that influence and reduce their vulnerability. In addition, these assessments can help design proactive mitigation plans to protect people and natural resources from adverse impacts on coastal areas (Hoque *et al*., 2019). All countries are at risk from climate change and may need to use policy instruments to strengthen adaptation and mitigation efforts (Edmonds *et al*., 2020). Participatory prospective analysis (PPA) is a tool to identify, study, and quickly anticipate changes with the participation of experts and stakeholders. This technique brings decision-makers together to analyse problems in an expert system that can reconstruct multiple plans using different approaches. Prospective analysis is performed to create sustainable scenarios in the future by identifying key factors that affect system performance (Bourgeois and Jésus, 2004).

Teluk Pangpang is an area that has high potential for capture fisheries in Banyuwangi Regency, with fish catches ranging from pelagic fish to demersal fish, which are caught using fishing gear such as handlines, nets, gill nets, bubu, lift nets, etc. Meanwhile, the community around Teluk Pangpang is dominated by fishermen who fall into the category of small-scale fisheries. Meanwhile, the community around Teluk Pangpang is dominated by fishermen who fall into the category of small-scale fisheries, so attention from various parties is required in order to improve welfare, especially for small-scale fishermen. Teluk Pangpang has also been designated as an essential ecosystem area for mangrove wetlands by the Governor of East Java Province, Indonesia. So this area is also referred to as a multi-use area because its potential is not only utilised for capture fisheries but also aquaculture and mangrove conservation (Setyaningrum *et al.*, 2024). Given the occurrence of climate change, it is necessary to assess coastal vulnerability to various hazards in the coastal area of Pangpang Bay as necessary information for effective management in disaster prevention. This study aims to analyse the overall coastal vulnerability of Pangpang Bay and quantify the vulnerability to various hazards by integrating six physical parameters using spatial techniques and formulating sustainability in the development of small-scale capture fisheries in Pangpang Bay, Banyuwangi Regency.

2. Materials and Methods

2.1 Materials

The materials used in this study are coastal areas and small-scale fishing communities in Pangpang Bay, Banyuwangi Regency. While the tool used is ArcGis software.

2.1.1 Ethical approval

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

2.2 Methods

The research method uses a descriptive method. The research approach in this study is a quantitative approach. Quantitative research can be interpreted as a research method based on the philosophy of positivism.

2.3 Location and Time of Study

The research location was carried out in Pangpang Bay, Banyuwangi Regency, which is geographically located between $8^0$27.052' – $8^0$32.098' South latitude and $114^0$20.988' – $114^0$21.747' East longitude. More precisely, the research location is in four coastal villages, namely Kedungringin, Wringinputih, Kedunggebang, and Tegaldlimo Villages, where the area is also limited to the Pangpang Bay mangrove wetland essential ecosystem area, which has been determined by the Governor of East Java in 2021. For research time, it was conducted from March to December 2023. A map of the research location can be seen in Figure 1.

2.4 Data Collection

The types of data used in the CVI analysis are geomorphology, erosion/accretion, coastal slope, distance of vegetation from the coast, wave height, and mean tidal range. For the data retrieval technique is from satellite imagery through geographic information systems, where data is taken within the last 10 years, from 2012 to 2021.

The type of data used in the PPA analysis is stakeholders with an interest in Pangpang Bay. The selection of respondents was carried out by considering various specific criteria in accordance with the research objectives, such as expert respondents or understanding the existing situation and problems as professional respondents or respondents who work directly in the field and are able to answer questions well, including representatives from of fishermen groups in the research location, stakeholders such as traders/middlemen, community leaders, related agencies, and village government organisations (20 respondents). Furthermore, data collection techniques Were used in focus group discussions (FGDs) with predetermined respondents, conducted at the Wringinputih Village office as a representation of the four research villages.

2.5 Analysis Data

This research method is descriptive *and uses* a quantitative approach. The analytical methods used were coastal vulnerability analysis (CVI) and participatory prospective analysis (PPA).

2.5.1 Coastal vulnerability

The coastal vulnerability of Bay Pangpang Banyuwangi Regency was analysed using coastal vulnerability analysis or what is called the Coastal Vulnerability Index (CVI). The variables used in determining the CVI used six variables as modified from (Hammar-Klose *et al*., 2003) and (Rachmadianti *et al.*, 2018), which are presented in Table 1. Each variable that has been assessed at each location is then averaged to produce a value that will be entered in the vulnerability index formula based on the calculation of the value of each variable through the equation below and produce a coastal vulnerability value.

$$CVI=\sqrt{\frac{a \times b \times c \times d \times e \times f}{6}} \quad \text{..............................(1)}$$

Where:

CVI = Coastal Vulnerability Index
a = Geomorphology
b = Erosion/Accretion (m)
c = Coastal slope (%)
d = Distance of plants from the beach (m)
e = Wave height (m)
f = Average tide range (m)

The CVI value has been obtained; then, the value determines the vulnerability category. If the CVI value is < 20.5 then the vulnerability category is "Low"; if the CVI value is 20.5 – 25.5, then the vulnerability category is "Medium"; if the CVI value is > 25.5 – 29, then the vulnerability category is "High", and if the CVI value is > 29 then the vulnerability category is "Very High" (Hammar-Klose *et al.*, 2003).

direct influence between factors enter a value from 0 – 3 (0 = no influence, 1 = little influence, 2 = moderate influence, 3 = strong influence) into the matrix. The results of matrix analysis from expert opinion are then processed using prospective analysis software. The results of the calculation are visualised in the diagram of influence and dependence between factors. Each quadrant in the diagram has different factor characteristics (Bourgeois and Jésus, 2004), namely: (a) Quadrant I (Determining Factors or Driving Variables). This quadrant includes factors that have a strong influence but less dependency. Factors in this quadrant determine or drive the variables that fall into the category of the most powerful factors in the system under study. (b) Quadrant II: Leverage variables. The factors included in this quadrant are called factors

Table 1. CVI assessment parameters

Variables 1		Very Low	Low	Medium	High	Very High
		2	3	4	5	
a	Geomorphology	Rocky cliff beaches	Medium cliff, rocky	Low cliff, rocky, alluvial plain	Gravel beach, estuary lagoon	Sand beach, coastal marsh, delta, mangrove, coral reefs
b	Erosion/accretion or shoreline change (m/year)	> 2	1 – 2	(-1) – 1	(-2) – (-1)	<(-2)
c	Coastal slope (%)	>1.2	1.2 – 0.9	0.9 – 0.6	0.6 – 0.3	<0.3
d	Distance of vegetation from the shore (m)	>600	200 – 600	100 – 200	100 – 50	<50
e	Wave height (m)	<0.55	0. 55 – 0.85	0.85 – 1.05	1.05 – 1.25	>1.25
f	Average tide range (m)	>6	4 – 6	2 – 4	1 – 2	<1

2.5.2 Participatory prospective analysis (PPA)

Participatory prospective analysis is conducted to create sustainable future scenarios by identifying key factors that influence system performance. On the other hand, for planning purposes, it is necessary to know the various influences of different variables on the system under study. In this way, variables that require intervention can be identified and serve as a starting point for effective planning and management. Stakeholders discussed and, based on a consensus assessment of the mutual influence between variables, analysed in a matrix using Excel software. Experts or stakeholders directly involved in determining the

or leverage variables. Factors in this quadrant are partly considered as strong factors or variables because they have a strong influence and dependence on each other. Factors in this quadrant may be considered as strong factors or variables. (c) Quadrant III (output variables). Factors in this quadrant represent output factors, where the influence is small, but the dependency is high. (d) Quadrant IV (marginal variables). Marginal variables whose influence is small and the level of dependence is also low, so these factors in the system are free.

The next step is morphological analysis. The policy scenario will be a model of sustainable small-scale capture fisheries, specifically providing for anticipated future changes. Scenario development begins with identifying the future state of the variables and then identifying the unlikely combinations of the variable states. Unlikely combinations of variable conditions were discarded from scenario development. Scenario development was conducted with structured group discussions. Stakeholders were asked to provide an assessment of the future status of each determining variable. The estimated future status of these variables can be used to create possible scenarios for small-scale fisheries management in Pangpang Bay, Banyuwangi Regency. Based on the likelihood of a situation occurring in the future, scenarios are categorised into three scenarios, as follows: Scenario-1 (Pessimistic), by making modest improvements to key attributes (factors). Scenario-2 (Moderate), by making improvements to about 50% of the key attributes (factors). Scenario-3 (Optimistic), by making improvements to all key attributes (factors).

3. Results and Discussion

3.1 Results

3.1.1 Coastal Vulnerability Index

The coastal area of Pangpang Bay is a greenbelt area or mangrove green belt, which is designated as one of the essential ecosystems in Indonesia. The width of the bay reaches about 3.5 km and has a water area of 3,000 ha. The Pangpang Bay area is also one of the places that is used as a livelihood for the surrounding community to fish around the mangroves and in the waters of the bay itself. The majority of people around Pangpang Bay work as fishermen and vannamei shrimp farmers.

Based on the results of spatial analysis, the values for physical parameters on the coastal vulnerability of Panpang Bay are obtained, where the results of coastal vulnerability analysis for Panpang Bay are included in the low category (Table 2). Values for geomorphological parameters, distance of plants from the coast and wave height fall into the category of highly vulnerable. As for the erosion/accretion and high tide parameters, the vulnerability value is in the normal category. The last is the value of the coastal slope parameter, which is in the category of very not vulnerable. Furthermore, for the results of the CVI analysis, the coastal area of Teluk Pangpang falls into the category of low vulnerability to climate change. Climate change has impacts such as weather anomalies, rainfall, storms, winds, and others. In this regard, with a fairly high coastal slope, the coast of Teluk Pangpang experiences minimal flooding. In addition, because of the bay waters, the tides are minimally influenced by the open ocean, so the tides of Pangpang Bay are at normal levels of vulnerability. Not only that, but mangrove plants along the Teluk Pangpang area continue to thrive in binding sediments. In fact, massive mangrove planting activities have resulted in the growth of mangroves becoming denser; the impact of wind coming to land tends to be blocked by mangroves so that erosion can be minimised. Instead, accretion occurs.

As for the variable of shoreline change, the analysis results show that in 2013 – 2023 most of them experienced erosion. Coastal areas that experienced erosion at Kedungasri Beach, Pangpang Bay pier, the end of Pangpang Bay area and Kedungasri Hamlet beach area. Accretion events only occur in the Cemara Beach area. Areas other than Cemara Beach experience erosion due to tidal movement and ocean waves, and in both cells there are also few mangroves that make the land area less protected from waves.

The coastal area of Pangpang Bay entirely has a type of beach whose coastal slope value is more than 1.20%, to be precise around 1.63-6.75%, so it is classified into the category of very low vulnerability. In addition, the distance from the coast of Pangpang Bay is less than 50 m so it is classified as very vulnerable. Significant loss of area and vegetation in coastal areas, as well as long distances between coastal-adapted plant species, indicate the inability of the beach sand system to absorb the impacts of disturbance. The impacts will be seen in the limited migration of sand to the inner beach, deterioration of natural ecosystems and erosion conditions. This results in a systemic imbalance that leads to reduced beach surface area and increased distance between dunes.

While the average value of significant wave height in the coastal area of Pangpang Bay from 2013 to 2023 shows a wave value of less than 1.25 m so it is classified as moderate or normal vulnerability. Significant wave height is the average height of one-third of the waves in the wave spectrum (trough to crest) over a period of time. The average value of tides in the coastal area of Pangpang Bay from 2013 to 2023 shows that the area experiences tidal events with a value of approximately 2.2 m annually and is classified as moderately vulnerable. The magnitude of tides affects changes in the coastline in coastal areas, because the continuous tidal events can change the surface of the seabed to the beach.

3.1.2 Sustainability of Small-Scale Capture Fisheries

The PPA analysis begins with the data collection process on the sustainability of small-scale fisheries by presenting around 20 representatives of stakeholders in a focus group discussion (FGD), then identifying key variables that affect the coastal area of Pangpang Bay. Based on brainstorming conducted with stakeholders, 12 variables that are considered influential in the sustainability of small-scale capture fisheries in Pangpang Bay, Banyuwangi Regency, were agreed upon (Table 3). The variables are the result of discussions and consensus reached by the stakeholder representatives. In this case, it is not yet known which variables are most decisive in the management of small-scale capture fisheries in Pangpang Bay, Banyuwangi Regency.

Group discussions and work were conducted using a consensus evaluation approach to analyse the influence or dependency of each variable on other variables. The results of the analysis in the form of a diagram of direct and indirect effects between variables are shown in Figure 2, where the distribution of variables in the space of four quadrants is separated by two axes. The analysis results show that the variables are scattered in quadrants II and III. In this case, the variables scattered in quadrant II are selected, as they represent the results of the direct and indirect impact analysis. While the variables in quadrant III represent output factors, where the influence is small, but the

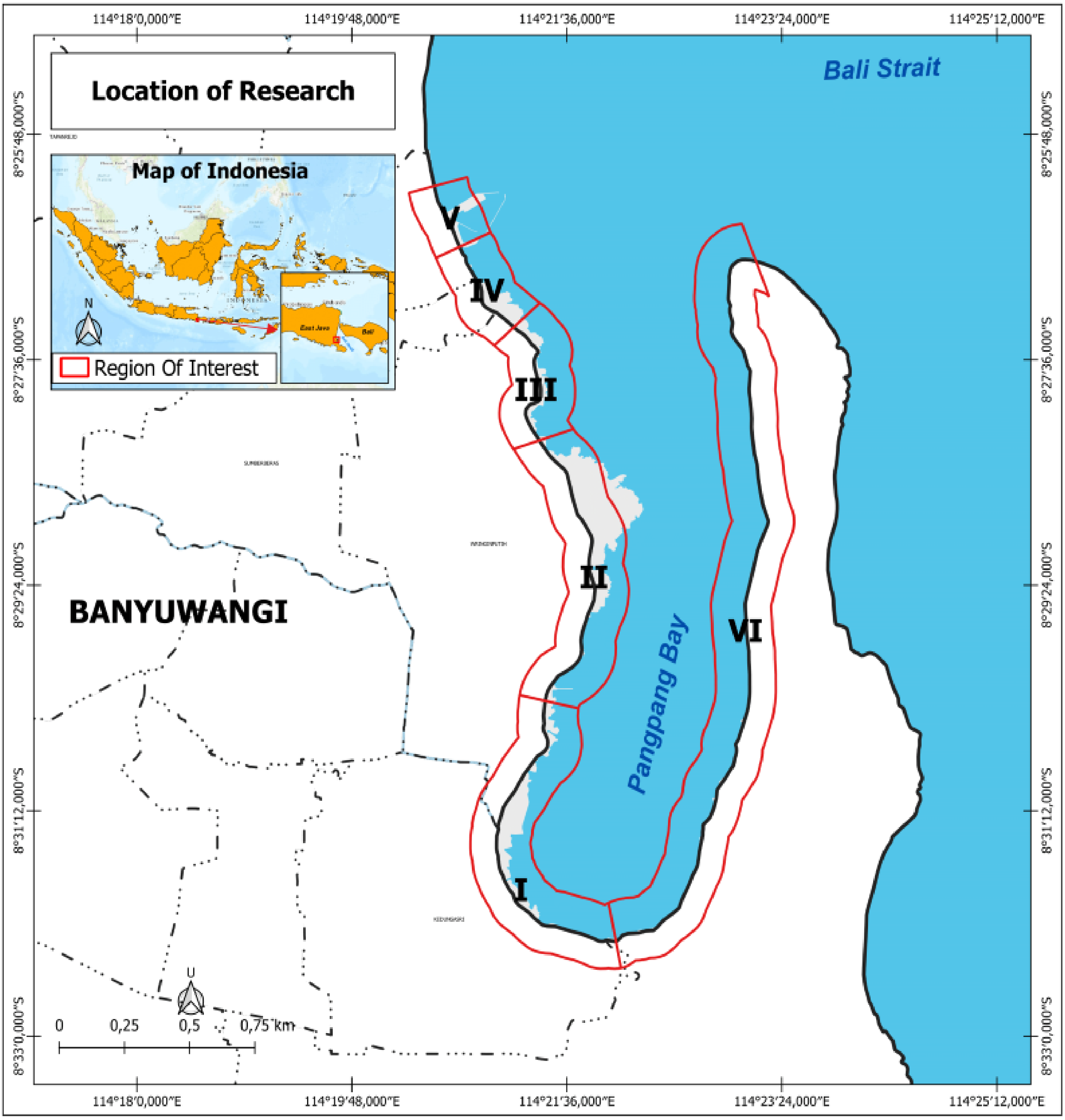

Figure 1. Research location.

dependency is high. The variables in quadrant II have a significant impact on the system, so they can be used as an entry point for effective management. The variables in question can be said to be the most influential variables on the system, namely climate change, coastal vulnerability, catch, mangrove area and density, number of small-scale fishermen, human resources of small-scale fishermen, and management of small-scale fisheries resources.

The selection of variables in quadrant II is also based on the weight value of global strength, as shown in Table 4, where variables number 1 to 7 are selected as the most influential variables, because the weight value is close to the value of 1 or more than 1. This means that the analysis of direct and indirect (total) influence shows that the seven variables in question are said to be the variables that most strongly influence the sustainability of small-scale capture fisheries

Table 2. Vulnerability index (VI) and coastal vulnerability index (CVI) scores in the coastal area of Pangpang Bay, Banyuwangi Regency

Lo-cation	Geo-mor-phology	VI	Erosion/ accre-tion (m/ year)	VI	Coast-al slope (%)	VI	Distance of veg-etation from the shore (m)	VI	Wave height (m)	VI	Aver-age tide range (m)	VI	CVI Value	Vulner-ability Catego-ry
I	Sandy, mud-dy, mangrove	5	0	3	2.3	1	0	5	1.4	5	2.2	3	13.7	Low
II	Sandy, mud-dy, mangrove	5	0	3	1.6	1	0	5	1.4	5	2.2	3	13.7	Low
III	Sandy, mud-dy, mangrove	5	14.4	1	2.8	1	0	5	1.4	5	2.2	3	7.9	Low
1V	Sandy	5	-0.9	3	6.7	1	0	5	1.4	5	2.2	3	13.7	Low
V	Sandy	5	-0.9	3	6.7	1	0	5	1.4	5	2.2	3	13.7	Low
VI	Sandy	5	-0.9	3	6.7	1	6	5	1.4	5	2.2	3	13.7	Low
CVI of Pangpang Bay													2.9	Low

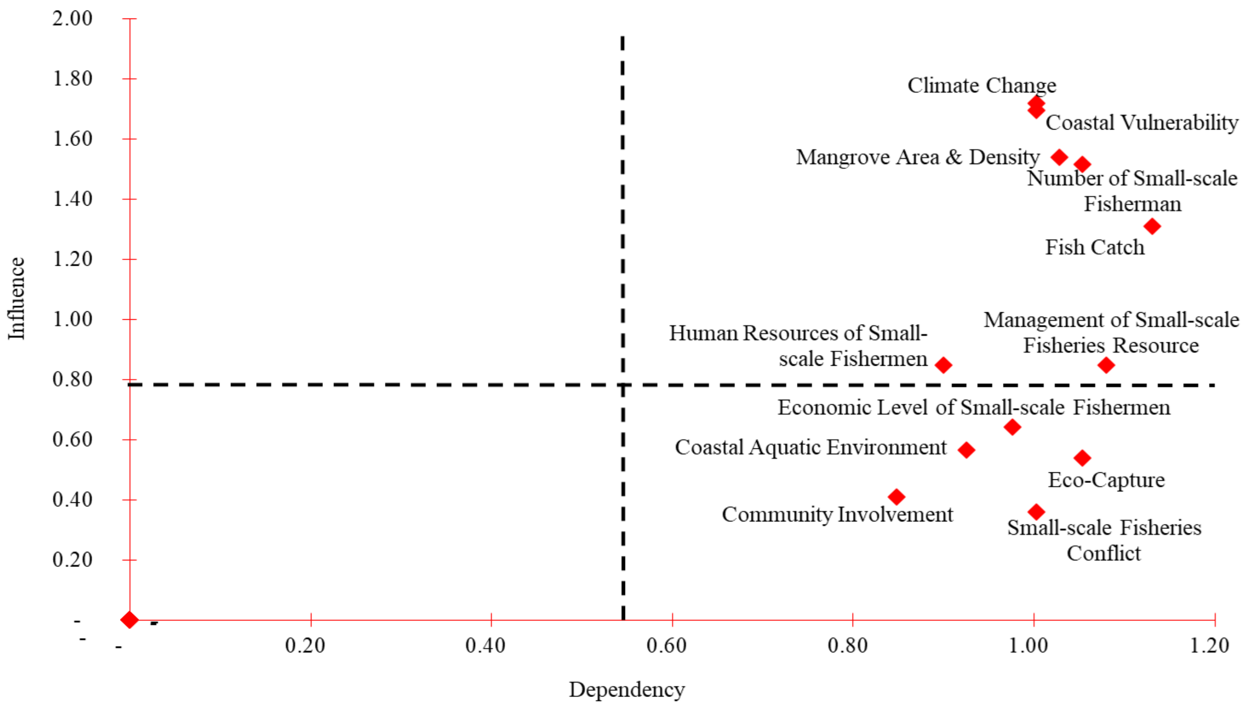

Figure 2. The results of analysis of direct and indirect influence between variables..

in Pangpang Bay.

on the estimated sea surface temperature (SST) trends

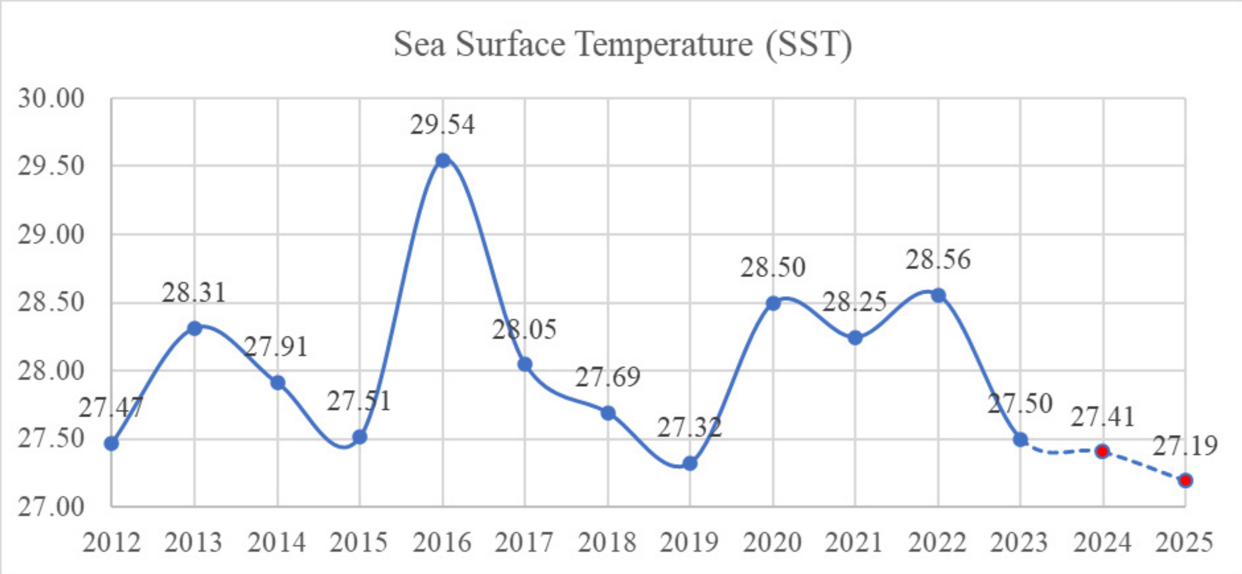

Figure 3. Sea surface temperature (SST) trend (Year 2022 – 2023) and SST forecast (Year 2024 – 2045) in Pangpang Bay, Banyuwangi Regency**.**

Based on the seven selected variables, stakeholder representatives then created scenarios for small-scale fisheries management planning in Teluk Pangpang, through FGDs to determine consensus in determining the possible conditions of these variables in the next 20 years (according to the time dimension of the analysis), while still referring to existing conditions (current data and conditions). The FGD resulted in the determination of variable conditions and their combinations (Table 5), where each variable was given a letter code (A to G) and the variable's future condition scenario was given a number code (1 to 4). Scenario development began by identifying combinations of variable conditions that were unlikely to occur. Combinations of variable conditions that are unlikely to occur are then discarded from scenario development. The combinations of variable conditions that are unlikely to occur are as follows: A1-B3, A1-C1, A1-D1, A2-B1, C3-F1, F2-G1, A1-G1, and D1-E3 Stakeholders' estimation results based on opinions and future reflections were not the same for all variables, namely: 1) Variables that have two possible forms of condition (mangrove area & density, human resources of small-scale fishers, and small-scale fisheries management); 2) Variables with three possible states (climate change, coastal vulnerability, and number of small-scale fishers); 3) Variables that have four forms of condition (catch).

In this case, the determinants of the conditions that are likely to occur in the next few years depend in the next few years. As shown in Figure 3, which is the SST data up to 2025 from the spatial analysis conducted. From the figure, it can be seen that the SST trend fluctuates until 2023, but the SST forecast until 2025 tends to remain at an average of 27^{0}C with differences in the numbers behind the comma, where the SST trend forecast tends to decrease until 2025. This shows that the scenario model of small-scale capture fisheries management in Pangpang Bay can be done by considering climate change and vulnerability as one of the dimensions in the sustainability analysis.

As a result of the next stage of the FGD, where stakeholders were asked to organise combinations of variables and conditions to create a series of scenarios, there was agreement on possible scenarios for sustainable management of small-scale fisheries in Pangpang Bay, Banyuwangi Regency (Table 6). Based on the scenarios developed by stakeholders, it is clear that the differences between scenarios have implications for the efforts needed to manage small-scale fisheries in Pangpang Bay. In the optimistic scenario, maximum improvement efforts must be made on all variables for the system to move in a better direction. Implicitly, this optimistic scenario seems to reflect the stakeholders' interest in achieving ideal future conditions. On the other hand, the highly pessimistic scenario suggests that if current conditions continue, no improvement is needed and the system will be worse off than it is now.

Compromising between the two extreme scenarios mentioned above, stakeholder representatives also developed a moderately pessimistic scenario. These two trade-off scenarios reflect the interests of stakeholders by considering the possibility of improving various decision variables. Logical initiatives that can be proposed by stakeholder representatives can be formulated into practical strategic implications and forward-looking actions.

The stakeholder representatives then conducted structured discussions based on a combination of various framework conditions and possible scenarios in the next 20 years to identify strategic implications and formulate a way forward. The action plan that stakeholders can take is to prepare for the future situation (proactively), either reactively, proactively or anticipatively. To develop an action plan, stakeholders compare scenarios as strategic implications and

Table 3. Most influential variables in the sustainability model of small-scale capture fisheries in Pangpang Bay

Variable	Definition
Coastal Vulnerability	There is an increase in damage to coastal areas due to various factors caused by human activities and natural factors
Climate Change	The phenomenon of global warming, where there is an increase in greenhouse gases in the atmospheric layer and lasts for a certain period of time
Number of Small-Scale Fishers	The number of people who work as fishermen to fulfil their needs, using vessels with a maximum size of 5 (five) gross tonnes (GT)
Catch	The number of fish species and other marine animals caught during fishing operations
Mangrove Area and Density	The extent and density of a community of trees or grasses growing in a coastal area as well as for individual plants growing in association with it
Coastal Water Environment	Waters that are the border of land and sea within 12 nautical miles of the coastline, which includes beaches, estuaries, bays, shallow waters, swamps/brackish areas, and lagoons
Environmentally Friendly Fishing	Eco-friendly fishing, i.e. the extent to which the gear does not damage the water bottom, the likelihood of gear loss, and its contribution to pollution
The Economic Level of Small-Scale Fishermen	Economic activities that result in an increase in income over a certain period for small-scale fishers
Human Resources of Small-Scale Fishers	The power of thinking and working power that exists in fishermen, which needs to be fostered and explored, and developed to be utilised as well as possible for the welfare of small-scale fishermen
Management of Small-Scale Fisheries Resource	Efforts undertaken by the government or other parties, ranging from information gathering, analysis, planning, consultation, decision-making, allocation of fish resources, and application and enforcement of laws and regulations in the field of small-scale fisheries in an integrated manner, directed towards achieving sustainable productivity of aquatic biological resources and agreed objectives
Small-Scale Fisheries Conflict	A struggle by different parties in a small-scale fishery for scarce resources such as value, status, power, authority, and so on, where the goal of those fighting is not only to gain an advantage, but also to subdue rivals by force or threat
Neighbourhood Community Involvement	The participation of the community or residents in various activities both locally and nationally, can occur voluntarily by force, encouragement or passively in a vertical or horizontal form

anticipatory actions so that stakeholders' needs can be met through interventions on various determining variables in the management of small-scale fisheries in Teluk Pangpang. In addition, assessing the future situation can also help prepare for reactive actions. By identifying and comparing scenarios, decision-makers and stakeholders can better plan for the future of the region.

Table 4. Weighted global variable strength score

Variable	Weighted Global Variable Strength
Climate Change	2.06
Coastal Vulenerability	2.02
Fish Catch	1.75
Mangrove Area and Density	1.69
Number of Small-Scale Fisherman	1.33
Human Resources of Small-Scale Fisherman	0.78
Management of Small-Scale Fisheries Resource	0.71
Coastal Water Environment	0.41
Eco-Capture	0.35
Economic Level of Small-scale Fishermen	0.48
Small-scale Fisheries Conflict	0.18
Community Involvement	0.25

In the last stage of the FGD, a consensus conclusion was reached, where strategic implications and anticipatory actions that need to be accommodated in the sustainable management of small-scale capture fisheries in Teluk Pangpang were formulated. Based on the key factors generated from the prospective analysis, a possible future condition was formulated by formulating a scenario for the sustainability of small-scale capture fisheries in Pangpang Bay, Banyuwangi Regency using Scenario-2 (Moderate), by improving around 50% of the key attributes (factors) (Table 7). In order to achieve sustainability of small-scale capture fisheries in Pangpang Bay, the scenarios are: 1) Seek to minimise the impact of climate change and conduct disaster mitigation to avoid increasing the value of coastal vulnerability to climate change, among others by expanding and closing mangrove forests in Pangpang Bay area; 2) Improve the human resources of small-scale fishermen through trainings such as environmentally friendly fishing training and alternative livelihood training, so that it will have an impact on shifting the livelihoods of small-scale fishermen which as a result the number of small-scale fishermen can be reduced, because they prefer to find a more decent job both in terms of income and social status that can improve the economy of small-scale fishermen; 3) There needs to be a common perception that is outlined in a commitment between all parties concerned with small-scale fishing communities.

If all of these can be realised, then the fish catch in Pangpang Bay will automatically increase, because the coastal water environment as a fish habitat is supportive, coupled with integrated and sustainable small-scale fisheries management involving all communities in Pangpang Bay (minimising conflict). In realising the scenarios described above, it is necessary to consider the budget or cost capabilities and the involvement of stakeholders who have the authority related to the attributes to be improved. Based on these considerations, it will have implications for achieving the ideal sustainability of small-scale capture fisheries in the Pangpang Bay area in a faster time.

The main framework, originally designed to foster social resilience, was expanded and used as a general heuristic to organise key resilience factors in fisheries systems. Resources that are able to withstand shocks or are impacted by change are classified as assets. Access to financial resources or technology are important social benefits, while healthy fish stocks and habitat diversity are important ecological assets.

3.2 Discussion

3.2.1 Physical vulnerability and Ecosystem Resilience

Coastal vulnerability, defined as the susceptibility of coastal areas to flooding and erosion caused by storms, post-tsunami cyclones, typhoons and tsunamis, is a major issue affecting most coastlines around the world and can be reflected in damage to property and infrastructure (Martínez *et al.*, 2020). Vulnerability assessments are the first step in informing policymakers about the underlying causes of coastal disasters (Kantamaneni *et al.*, 2019). The Coastal Vulnerability Index allows the assessment of variables measured through vulnerability to physical changes due to climate change. By generating statistical data, the index can highlight coastal areas that are particularly vulnerable and expected to be most affected by climate change and sea level rise (Pethick and Crooks, 2000).

Table 5. Consensus defined variable state

Variable	Variable Code	Possible State in the Next 20 Years			
		1	2	3	4
Climate Change	A	Increased	Fixed	Decreased	-
Coastal Vulenerability	B	Increased	Fixed	Decreased	-
Fish Catch	C	Increased	Fixed	Decreased	Fluctu-ate
Mangrove Area & Density	D	Increased	Fixed	-	-
Number of Small-Scale Fishermen	E	Increased	Fixed	Decreased	-
Human Resources of Small-Scale Fishermen	F	Increased	Fixed	-	-
Management of Small-Scale Fisheries Resource	G	Increased	Fixed	-	-

Table 6. Tabulation of scenario formulation

Scenario	Combination	Description
Optimistic (The best possible and desirable scenario, where change is gradual)	A3-B3-C1-D1-E3-F1-G1	Climate change (decreasing), coastal vulnerability (decreasing), catch (increasing), mangrove area and density (increasing), number of small-scale fishermen (decreasing), human resources of small-scale fisheries (increasing), management of small-scale fisheries resources (increasing)
Moderate (Scenario of relatively small or fixed changes, so that it is closer to a relatively good existing condition)	A2-B3-C2-D1-E2-F1-G1	Climate change (fixed), coastal vulnerability (decreasing), catch (fixed), mangrove area and density (increasing), number of small-scale fishers (fixed), human resources of small-scale fishers (increasing), SD management of small-scale fisheries (increasing)
Pessimistic (Scenario changes from existing conditions are difficult to predict, or existing conditions change downward)	A1-B2-C4-D2-E2-F2-G2	Climate change (increasing), coastal vulnerability (fixed), catch (fluctuate), mangrove area and density (fixed), number of small-scale fishers (fixed), human resources of small-scale fisheries (fixed), management of small-scale fisheries (fixed)
Very Pessimistic (Scenario of change from existing conditions to worse)	A1-B1-C3-D2-E1-F2-G2	Climate change (decrease), coastal vulnerability (decrease), catch (increase), mangrove area and density (increase), number of small-scale fishers (decrease), human resources of small-scale fisheries (fixed), management of small-scale fisheries (fixed)

Vulnerability to hazards and the level of disaster risk depend on the nature of the area and the level of preparedness. Technological approaches can address coastal hazards and reduce community vulnerability. For example, coastal defences can be designed using soft or hard engineering to minimise or even eliminate hazards, thereby protecting the local population, although this can be costly (Wang *et al*., 2014). Based on the results of FGDs conducted with fishermen and stakeholders in Pangpang Bay, the development of the coast of Pangpang Bay can be seen starting from the 1990s, when mangrove forests were cut down and converted into shrimp ponds. In the

2000s, many ponds were abandoned because shrimp production continued to decline due to disease, so the bay coast experienced high degradation. It wasn't until 2011 that the local community realised that to protect the coast from erosion and flooding, mangroves needed to be planted regularly. As a result, mangroves now grow thick and wide, almost along the coast of Pangpang Bay.

affects the muddy bottom of the bay. In addition, there are some areas that are not covered by mangroves, where the area is not rocky and has gentle terrain, but the interior is characterised by a component of fine sand. Castro and Silveira (2020) explained, mangrove forests with little reproductive structure are particularly vulnerable because their populations are not renewed, and mangrove forests with low sedimentation rates are vulnerable to sea level rise because they may not be able to cope with rapid sea level rise. Therefore, they are classified as highly vulnerable.

Table 7. Strategic implications and plan of action in management of small-scale fisheries in Pangpang Bay, Banyuwangi Regency

Scenario Comparison	Policy Implications	Plan of Action
Optimis – Moderat	- Reducing the impact of climate change	- Socialisation and training on disaster mitigation in the coastal area of Pangpang Bay in a massive and structured manner - Involve all parties in the implementation of the above activities
	- Improving the human resources of small-scale fishermen	- Provide training on technological developments, such as catch processing and cultivation training, etc.
	- Encourage community participation and openness, especially in preventing environmental pollution	- Improved community empowerment programmes - Improved information services and access (information disclosure)
Pessimistic – Very Pessimistic	- Improve coordination and communication between stakeholders	- Improved institutional coordination
	- Encourage regulatory implementation and law enforcement	- Improved socialisation of programmes/regulations

Higher vulnerability occurs in areas with high vulnerability and low adaptive capacity. In relation to the physical variables used in the vulnerability model, beaches that are considered more vulnerable are characterised as follows: Shorter beach widths, higher significant wave heights, potential gradients of shoreline deviation indicative of erosion, and lower slopes and elevations (Serafim *et al.*, 2019). With massive mangrove planting activities and mangroves growing densely, the wind coming to land tends to be blocked by mangroves so that erosion can be minimised, and even accretion occurs. As explained by (Kantamaneni *et al.*, 2019) coastal cells with no vegetation will be more vulnerable than cells with vegetation.

Based on Table 2, the geomorphological variables show that all coastal areas have a very high vulnerability score. This is because almost all coastal areas of Teluk Pangpang have mangroves. Because there are mangroves, most of them are muddy, and it also

Utilising ecosystems to protect and control coastal erosion and preserve natural habitats with or without hard structures has received worldwide attention through various conceptual ideas, such as building with nature or living beaches (Morris *et al.*, 2018) such as sand dunes, saltmarsh, mangroves, seagrass and kelp beds, and coral and shellfish reefs, to provide coastal protection in place of (or to complement. This means that mangroves can play a role in reducing coastal erosion, even when waves are high. Vegetation structures, especially taproots and pneumatophores, generate drag that dissipates wave energy, facilitating sediment deposition and in turn favouring sediment retention (Sánchez-Núñez *et al.*, 2019).

3.2.2 Analysis of Socio-environmental factors in sustainability

The results of coastal slope analyses can identify and predict areas that will be lost due to the impacts of future sea level rise. Therefore, beaches that have a low slope between less than 0.3% have a very high vulnerability, if in the event of sea level rise and large waves, the coastal area will be lost due to the impact of a future sea level rise (Irham *et al*., 2021). Mohd *et al.* (2019) explained that slope is closely related to the vulnerability of coastal typologies to flood risk due to sea level rise. The steeper the slope of a coastal typology unit, the greater the likelihood that seawater will flood the coastal area during sea level rise, storm surges, tsunamis and storms. This is in accordance with the opinion of Kumar *et al.* (2010) that coastal slopes characterised by steepness or slope are associated with inundation caused by floods, tsunamis and storms.

Results from coastal elevation analyses can identify and predict areas that will be lost due to future sea level rise impacts. Therefore, beaches that have low elevations between 0 to 5 m above sea level have a very high vulnerability in the event of sea level rise and large waves (Irham *et al*., 2021). Beach slope is defined as the change in elevation over a horizontal distance at two points on the beach. Strong slopes are characterised by high values and gentler slopes by lower values. A flood-prone beach depends largely on how steep or flat it is. A gentle coastal slope has a greater ability to penetrate seawater onto land, whereas land with a steep slope has a very low ability to penetrate seawater due to wave energy dissipation. Therefore, the lower the land slope, the greater the possibility of land loss (Parthasarathy *et al*., 2022).

The distance of the beach from the bay, which can be a basis for considering the vulnerability of the coastal area, also shows that the beach edge has lost its ability to regulate sediment flow between the beach and the inner dunes (Alonso *et al*., 2018). Furthermore, according to Smith and Basurto (2019), it is associated with a significant increase in the distance between trees on windward-facing beachfronts. This change is largely related to tourism development (coastal and urban facilities), which alters wind patterns and accelerates sediment dynamics along the coast.

Numerical wave modelling has a major impact on the final results of vulnerability assessments. When assigning weights, experts consider significant wave height to be the second largest influence factor on coastal vulnerability. The possibility of shoreline displacement is also very important (Serafim and Bonetti, 2017). Significant wave height is used as an alternative to wave energy and is important for studying coastal vulnerability. In general, wave height is considered to limit coastal vulnerability. As wave height increases, wave energy also increases, resulting in land loss due to increased erosion and flooding along the coast. Therefore, coastal areas with high wave height are considered high risk, and areas with low wave height are considered low risk (Mahapatra *et al*., 2015).

Higher tidal ranges are associated with stronger tidal currents and more frequent flooding, leading to greater erosion and sediment transport. Therefore, it is possible to associate macro tidal beaches with more vulnerable conditions compared to micro tidal beaches, e.g. tidal range less than 1 m means higher vulnerability, very low vulnerability (level 1) and tidal range greater than 6 m means very high vulnerability (level 5) (Koroglu *et al*., 2019). Micro-tidal beaches are more vulnerable compared to macro-tidal beaches, mainly because the sea surface is always close to the tide in micro-tidal environments. Therefore, during storms, coastal flooding is easier to occur in micro tidal flats compared to macro tidal flats (Hoque *et al*., 2019). This approach associates large tidal zones (e.g. more than 6 m) with very low vulnerability (level 1) and small tidal zones (e.g. less than 1 m) with very high vulnerability (level 5). A simpler classification is provided by other authors who only distinguish between macro (level 1), mesotidal (level 3) and micro (level 5) environments (Buitrago *et al*., 2020).

3.2.3 Strategic Management and Future Scenarios

Due to the vulnerability of small-scale capture fisheries, sustainability in relation to this is also necessary, especially when it comes to climate change. In this case it is closely related to organizations from all sectors working to increase resilience in the face of increasing climate change impacts (Camp *et al*., 2020). This plan provides input for disaster mitigation and climate change adaptation in various fields, including agriculture, fisheries, and urban planning. Particularly helpful is recent research conceptualising fisheries resilience. Examples include fisheries management systems, and coastal communities associated with fisheries in general. However, a more comprehensive conceptualisation of resilience is still in its infancy (Mcleod *et al*., 2019). To help stakeholders set long-term goals and prioritise actions to increase resilience, there are two pathways to resilience: a) The ecology inherent in small-scale fisheries, as well as building assets and strengthening communities; b) Securing and enhancing the economic assets of effective governance, as evidenced by urban development and thriving fisheries. A new conceptual framework has been developed directly to identify feasible approaches, pathways and tools for increasing resilience to climate change in fisheries systems (Eurich *et al*., 2024).

Resilience in ecological, socio-economic, and governance aspects of the fisheries system, categorised into five domains: 1) Assets, which are the number and diversity of assets, as well as their stability across the system; 2) Flexibility, is the ability to change strategies or make adjustments in response to changing circumstances; 3) Organisation, is the socio-economic relationships, networks and institutions that operate at different spatial and temporal scales; 4) Learning, is the process by which individuals and organisations identify and evaluate the causes of change; and 5) Agency, is the ability and freedom of communities to make decisions and act in accordance with those decisions, and supports the ability of communities to operationalise various aspects of resilience. Based on this explanation, in addition to social capital, organisation also includes the connectivity of ecosystem components and the ability to support the movement, dispersal and flow of fish populations. Learning and organisation, on the other hand, relate only to socioeconomic aspects and fisheries governance (Cinner and Barnes, 2019).

Fisheries are complex social-ecological systems, and climate change impacts the natural and human factors that drive these systems. In particular, climate change affects the metabolism, growth and life history of marine organisms, which in turn affects fisheries and the communities that depend on these resources (Free *et al*., 2019). By promoting participatory approaches, social resilience is strengthened by encompassing multiple perspectives and objectives at all levels, including community and global levels (Carroll *et al*., 2023). The need to understand the resilience of socio-ecological systems with fisheries-specific parameters is to integrate the three dimensions that characterise climate-resilient fisheries, namely ecological, socio-economic and governance (Mason *et al*., 2022).

Resilience in fisheries systems is the ability to prepare, adapt, cope, and resist to ensure not only human interests but also the sustainability of fisheries resources and marine ecosystems. Knowing and understanding the inherent resilience of natural and human systems, including the maintenance of essential functions, their identity and structure, as well as the magnitude of anticipated impacts, will improve the responses and interventions required in the evaluation of fisheries and marine ecosystems (Eurich *et al*., 2024). Building resilience is particularly important in the context of climate change, as it involves preparation, resistance and limitation of stressors, recovery, and adaptation to ensure the sustainability of marine ecosystem services, fisheries resources, or the marine environment, and human interest (Mason *et al*., 2022).

Small-scale fisheries are an important economic factor, but their impact on poverty alleviation remains unclear. Some fishers struggle with poverty, and actions taken by those who have worked hard may not be enough to alleviate their situation and could potentially make things worse. Breaking out of the poverty trap in the fisheries sector may require efforts beyond individual capacity, especially given the prevalence of overfishing. In developing countries, vulnerable fisheries often occur due to various factors, such as overfishing, climate change, and increasing habitat loss, resulting in low incomes (Damasio *et al*., 2023). Fish populations and ecosystems are affected by resilience traits. This influences changes in the size and structure of fish populations in response to climate stress. As an example in fishing systems, population density creates a link between ecological and socio-economic aspects, i.e. fish that can be caught and consumed as a food source or exchanged for income or other assets. Therefore, fundamental features of effective fisheries management include maintaining healthy populations of fish species and ensuring that the benefits of fishing are utilised and distributed equitably (Free *et al*., 2020).

4. Conclusion

The coastal vulnerability level of Teluk Pangpang Banyuwangi Regency is categorised as low vulnerability to climate change. According to the results of the PPA analysis, there are seven variables that most affect the sustainability of small-scale fisheries in Pangpang Bay, namely climate change, coastal vulnerability, mangrove area and density, number of small-scale fishers, catches, human resources of small-scale fisheries, and management of small-scale fisheries resources. The formulation of sustainability scenarios is to minimise the impact of climate change, conduct disaster mitigation, improve human resources of small-scale fisheries, and equalise perceptions as outlined in the commitment between all parties.

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The writing team stated that there was no conflict of interest in the preparation of this article, and all teams agreed to publish the journal.

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