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ECOLOGICAL RECOVERY AND PERSISTENT LIVELIHOOD VULNERABILITY IN THE PANGPANG BAY MANGROVE SOCIAL–ECOLOGICAL SYSTEM, BANYUWANGI, INDONESIA

PEMULIHAN EKOLOGIS DAN KERENTANAN PENGHIDUPAN YANG PERSISTEN DALAM SISTEM SOSIAL-EKOLOGIS MANGROVE TELUK PANGPANG, BANYUWANGI, INDONESIA

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ABSTRACT

Mangrove restoration may improve ecological conditions without necessarily reducing livelihood vulnerability among coastal households. This study examines the relationship between ecological recovery and household vulnerability in Pangpang Bay, Banyuwangi, Indonesia, using the household component of the Social–Ecological System Vulnerability Index for Mangrove Ecosystems (SESVIME). The household component was applied because exposure, sensitivity, ecosystem dependence, and adaptive capacity were measured directly, whereas ecological indicators were derived from secondary monitoring with different spatial and temporal units. Structured interviews with 56 households in Muncar and Tegaldlimo were conducted from May to August 2026 and triangulated with restoration records and published ecological data. Household indicators were normalized to a 0–1 scale. A diagnostic additive vulnerability benchmark, [exposure + sensitivity + (1 − adaptive capacity)]/3, was compared with ordered self-perceived vulnerability using Spearman correlation. Mangrove extent increased from 643.35 ha in 2015 to 737.51 ha in 2023, while 76.8% of respondents perceived improving mangrove conditions. However, ecosystem dependence and income insecurity remained high. The additive benchmark averaged 0.603 and showed no association with self-perceived vulnerability ($\rho = -0.016$; $p = 0.910$). Given the small, nonrepresentative sample, these findings are exploratory and support integrating ecological restoration with livelihood, financial, informational, and institutional strengthening.

Keywords: social-ecological system, livelihood vulnerability, mangrove recovery, adaptive capacity, Pangpang Bay.

ABSTRAK

Restorasi mangrove dapat meningkatkan kondisi ekologis tanpa otomatis mengurangi kerentanan penghidupan rumah tangga pesisir. Penelitian ini mengkaji hubungan antara pemulihan ekologis dan kerentanan rumah tangga di Teluk Pangpang, Banyuwangi, Indonesia, dengan menggunakan komponen rumah tangga dari *Social-Ecological System Vulnerability Index for Mangrove Ecosystems (SESVIME).* Komponen rumah tangga digunakan karena keterpaparan, sensitivitas, ketergantungan terhadap ekosistem, dan kapasitas adaptif diukur secara langsung, sedangkan indikator ekologis diperoleh dari pemantauan sekunder dengan unit spasial dan temporal yang berbeda. Wawancara terstruktur terhadap 56 rumah tangga di Muncar dan Tegaldlimo pada Mei–Agustus 2026 dan ditriangulasi dengan catatan restorasi serta data ekologis yang telah dipublikasikan. Indikator rumah tangga dinormalisasi pada skala 0–1. Indeks kerentanan aditif diagnostik, [keterpaparan + sensitivitas + (1 − kapasitas adaptif)]/3, dibandingkan dengan kerentanan yang dirasakan responden menggunakan korelasi Spearman. Luas mangrove meningkat dari 643,35 ha pada 2015 menjadi 737,51 ha pada 2023, sementara 76,8% responden menilai kondisi mangrove membaik. Namun, ketergantungan terhadap ekosistem dan ketidakamanan pendapatan tetap tinggi. Indeks aditif rata-rata sebesar 0,603 dan tidak menunjukkan hubungan dengan kerentanan yang dirasakan responden ($\rho = -0,016$; $p = 0,910$).

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Mengingat ukuran sampel kecil dan tidak representatif, temuan ini bersifat eksploratif dan mendukung integrasi restorasi ekologis dengan penguatan penghidupan, finansial, informasi, dan kelembagaan.

Kata kunci: sistem sosial-ekologi, kerentanan penghidupan, pemulihan ekosistem mangrove, kapasitas adaptif, Teluk Pangpang.

INTRODUCTION

Mangrove ecosystems support coastal fisheries by providing nursery and feeding habitats, shoreline protection, carbon storage, and other ecosystem services that contribute to coastal livelihoods. These functions are particularly important in Indonesia, where many coastal households depend directly or indirectly on fisheries and mangrove resources for income and food security (Donato et al., 2011; Murdiyarso et al., 2015; Hochard et al., 2019). Mangrove restoration has therefore become an important management response intended not only to improve ecological condition but also to sustain fisheries-based livelihoods and other coastal economic activities (Arifanti et al., 2022; Hagger et al., 2022; Sasmito et al., 2023).

However, evidence from previous studies indicates that ecological recovery does not necessarily produce proportional improvements in fisheries-based income or household livelihood security. In several mangrove-dependent communities, livelihood outcomes have been shaped by the degree of resource dependence, exposure to environmental and climatic disturbances, access to alternative income sources, and institutional support (Nyangoko et al., 2022; Yamamoto, 2023; Ebeler et al., 2025; Dulyakasem et al., 2026). These findings should not be interpreted as universal conditions for all mangrove-dependent communities. Rather, they suggest that the social benefits of restoration are context-dependent and may vary according to local livelihood structures, household assets, and adaptive capacity. Whether similar constraints persist in Pangpang Bay despite documented ecological recovery is therefore an empirical question examined in this study.

This issue remains insufficiently addressed in conventional vulnerability assessments. Vulnerability is commonly conceptualized through exposure, sensitivity, and adaptive capacity (Turner et al., 2003; Adger, 2006), while social–ecological systems research emphasizes feedbacks and interdependence between human and ecological subsystems (Ostrom, 2009). Yet many composite assessments still provide limited explanation of how changes in ecosystem condition are transmitted into household welfare, particularly in coastal fisheries economies where ecological benefits, livelihood dependence, and adaptation may operate simultaneously (Mafi-Gholami et al., 2021). This creates a methodological gap: ecological recovery may improve the resource base on which fisheries depend, but highly dependent households may remain vulnerable if income is seasonal, occupational alternatives are limited, financial buffers are weak, or institutional support is insufficient.

Pangpang Bay, Banyuwangi, East Java, provides an appropriate setting to examine this relationship. Independent remote sensing and field monitoring indicate improvements in mangrove extent and condition between 2015 and 2023, while surrounding coastal households remain closely

connected to capture fisheries, aquaculture, and other activities that depend on coastal resources (Hidayah et al., 2024). Rather than assuming that livelihood vulnerability persists because mangrove-dependent communities are inherently vulnerable, this study directly assesses household exposure, sensitivity, ecosystem dependence, and adaptive capacity. It addresses three questions: (1) how documented ecological recovery coexists with household exposure, sensitivity, ecosystem dependence, and adaptive capacity; (2) how human–mangrove dependence mediates the relationship between environmental change and livelihood security; and (3) to what extent a conventional additive vulnerability index corresponds with residents' self-perceived vulnerability.

The scientific contribution of this study lies in evaluating ecological recovery and livelihood vulnerability within the same social–ecological system rather than assuming that improvements in mangrove condition automatically generate social resilience. The study conceptualizes ecosystem dependence as a transmission pathway through which ecological change can influence household welfare and empirically examines whether conventional additive vulnerability accounting corresponds with locally experienced vulnerability. By integrating household vulnerability dimensions with independently documented ecological recovery, the study operationalizes the household component of the Social–Ecological System Vulnerability Index for Mangrove Ecosystems (SESVIME) as a relational assessment framework. This approach provides an empirical basis for examining a potential recovery–vulnerability paradox while recognizing that such a pattern must be interpreted in relation to the specific livelihood and institutional context of Pangpang Bay.

RESEARCH METHODS

Study Area and Site Selection

The study was conducted in Muncar and Tegaldlimo subdistricts, which form two spatially distinct coastal settings directly connected to the Pangpang Bay mangrove social–ecological system in Banyuwangi Regency, East Java, Indonesia (Figure 1). Pangpang Bay is a semi-enclosed coastal system characterized by dense mangrove vegetation and aquaculture ponds located adjacent to the mangrove margins, which demonstrates a direct spatial linkage between ecological condition and coastal resource use (Hidayah et al., 2024). A recent study shows that the bay supports multiple resource uses, including small-scale capture fisheries, Pacific white shrimp farming, and mangrove conservation, while its fisheries are exposed to coastal and climate-related vulnerability (Setyaningrum et al., 2025).

Site selection followed three criteria: (1) direct spatial adjacency to the Pangpang Bay mangrove system; (2) documented dependence on fisheries, aquaculture, or mangrove-associated livelihood activities; and (3) the presence of contrasting livelihood characteristics that allow household vulnerability to be examined across different coastal settings within the same social–ecological system. Muncar represents the northern part of the bay and is strongly characterized by capture-fisheries activity centered on the Muncar Coastal Fishing Port, which plays an important role in local fish landings and the coastal economy (Nazhoom & Wijaya, 2025). Tegaldlimo represents

the southern part of the bay, where pond aquaculture and mangrove-associated production systems are more prominent, including fish, shrimp, and mud-crab cultivation linked to silvofishery practices (Hidayat & Purwanto, 2024).

The two sites were therefore selected to capture analytical variation in livelihood dependence and exposure within the same mangrove social–ecological system rather than to provide statistically representative coverage of all communities surrounding Pangpang Bay. Potential differences in livelihood dependence and environmental exposure were not assumed a priori; these dimensions were measured at the household level using standardized exposure, sensitivity, dependence, and adaptive-capacity indicators and were subsequently compared between Muncar and Tegaldlimo using nonparametric tests. Accordingly, the two-site design provides a comparative analytical basis for examining how contrasting coastal livelihood settings are associated with household vulnerability, while broader population-level generalization remains limited by the nonprobability sampling design.

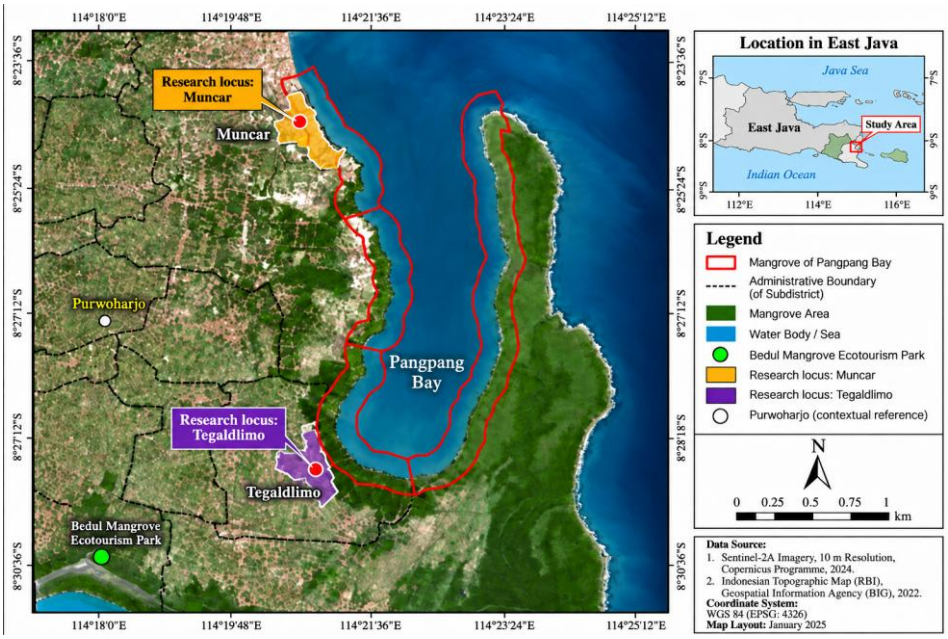

Figure 1. Location of the Study Area

Data Sources and Sampling

The study combined primary household data with complementary restoration and ecological information. Primary data were collected through face-to-face structured interviews conducted from May to August 2026. Respondents were selected using criterion-based nonprobability sampling to identify households with direct livelihood or social–ecological linkages to the Pangpang Bay coastal and mangrove system. Eligible respondents were household members who were knowledgeable about household socioeconomic conditions, livelihood strategies, dependence on coastal and mangrove resources, and perceived environmental change. The final analytical sample comprised 56 completed interviews (Table 1), including 37 respondents from Muncar and 19 from Tegaldlimo. The sample size was not derived from a probability-based population formula; rather, it represented the completed eligible household interviews available for the household-level SESVIME analysis.

Accordingly, the findings are interpreted as exploratory evidence and not as statistically representative estimates of the wider population.

The sample included the principal coastal livelihood groups encountered in the study locations: 35 capture fishers (62.5%), 13 aquaculture or pond farmers (23.2%), and 8 respondents engaged in other occupations (14.3%). Livelihood dependence and environmental exposure were not used as predetermined sampling strata because these were analytical outcomes measured through the survey. Instead, standardized indicators were used to assess exposure, sensitivity, ecosystem dependence, and adaptive capacity, while potential differences between Muncar and Tegaldlimo were examined subsequently using nonparametric comparisons.

The questionnaire collected information on household socioeconomic characteristics, coastal and climatic exposure, livelihood sensitivity, ecosystem dependence, adaptive capacity, self-perceived social–ecological vulnerability, conservation-incentive preferences, and perceived environmental and livelihood change. All participants provided informed consent, and the study received ethical approval from the Ethics Committee on Social Studies and Humanities, National Research and Innovation Agency (BRIN), Indonesia (No. 355/KE.01/SK/05/2026).

Two secondary data sources were used for triangulation. Local administrative records provided information on restoration activities, community organizations, training, livelihood programs, and institutional interventions. Published ecological monitoring based on Sentinel-2 imagery and field observations provided independent evidence of changes in mangrove extent and condition in Pangpang Bay (Hidayah et al., 2024). These ecological data were used to establish the broader ecological trajectory rather than being directly incorporated into household vulnerability scores because their spatial and temporal units differed from those of the 2026 household survey.

Table 1. Respondent Characteristics (*n* = 56)

Characteristic	Category/Statistic	*n* or mean	% or *SD*
Subdistrict	Muncar	37	66.1
	Tegaldlimo	19	33.9
Gender	Male	52	92.9
	Female	4	7.1
Age (years)	Mean	47.98	10.85
Years residing in area	Mean	39.36	16.09
Household size	Mean	4.04	1.28
Education	Primary school or less	20	35.7
	Junior secondary	15	26.8
	Senior secondary	18	32.1
	Bachelor’s degree	3	5.4
Primary occupation	Capture fisher	35	62.5
	Aquaculture/pond farming	13	23.2
	Other	8	14.3
Monthly household income	≤ IDR2,000,000	20	35.7
	IDR2,000,001-IDR3,500,000	24	42.9

Characteristic	Category/Statistic	*n* or mean	% or *SD*
	> IDR3,500,000	12	21.4
Seasonal household income	Yes	51	91.1
Emergency savings	Yes	25	44.6
Received coastal/mangrove/fishery/environmental assistance	Yes	29	51.8

Source: Primary Data Processed (2026)

SESVIME Conceptual and Household Modules

The Social-Ecological System Vulnerability Index for Mangrove Ecosystems (SESVIME) is used in this study as a conceptual framework for organizing the relationships among ecological condition, household vulnerability, ecosystem dependence, and adaptive capacity. Conceptually, SESVIME distinguishes exposure (E), ecological sensitivity (S_E), household sensitivity (S_H), human–ecosystem coupling (C_HE), ecological adaptive capacity (AC_E), and human and social–institutional adaptive capacity (AC_H):

$$SESVIME = f(E, S_E, S_H, C_HE, AC_E, AC_H) \quad (1)$$

This formulation represents the proposed architecture of SESVIME rather than an empirically calibrated index in the present study. In the full conceptual framework, human–ecosystem coupling is directional, including ecosystem-to-human dependence and human-to-ecosystem pressure or stewardship. Ecological and household sensitivities and adaptive capacities are also treated as distinct but interacting components. However, the available data did not provide household-compatible measures of ecological sensitivity, ecological adaptive capacity, or an independent human-to-ecosystem pressure or stewardship construct. Consequently, the full SESVIME formulation was not estimated or validated in this study.

The empirical analysis therefore focuses exclusively on the household component of the framework. Four household-level dimensions were operationalized: perceived exposure (E_H), household sensitivity (S_H), ecosystem-to-human dependence (D_E→H), and household adaptive capacity (AC_H). These dimensions were measured directly from the household survey and analyzed independently and relationally to examine how ecological recovery may coexist with continued livelihood vulnerability.

For methodological comparison, a conventional additive household vulnerability benchmark was calculated as:

$$V_add = [E_H + S_H + (1 - AC_H)] / 3 \quad (2)$$

The additive benchmark is not interpreted as the SESVIME score. It is used only as a diagnostic comparator to examine whether a conventional compensatory aggregation of exposure, sensitivity, and adaptive capacity corresponds with respondents' self-perceived vulnerability. The empirical objective of the present study is therefore to evaluate the household vulnerability relationships that inform SESVIME development, rather than to validate the full SESVIME index.

Household Indicators and Statistical Analysis

The empirical household module comprised four dimensions: perceived exposure (E_H), household sensitivity (S_H), ecosystem-to-human dependence (D_E→H), and household adaptive capacity (AC_H). Perceived exposure was calculated from Q34–Q37, household sensitivity from Q44–Q48, and adaptive capacity from Q58–Q62. Responses measured on five-point ordinal scales were normalized to a common 0–1 scale using $(x - 1)/4$, with higher values indicating greater exposure, sensitivity, or adaptive capacity, as applicable. Internal consistency of the multi-item constructs was evaluated using Cronbach's alpha (Table 2).

Ecosystem-to-human dependence (D_E→H) was treated as a formative rather than reflective construct and was operationalized using two complementary dimensions. Q38 measured resource reliance, namely the degree to which the household depends directly on coastal and mangrove resources, whereas Q39 measured the economic consequence of ecosystem deterioration, expressed as the expected disruption to household income if mangrove conditions declined. These dimensions are conceptually distinct but jointly represent the strength of the pathway through which changes in mangrove condition may affect household welfare. Similar livelihood studies emphasize that ecosystem dependence involves both the extent of reliance on ecosystem-based activities and the consequences for household welfare when ecosystem services deteriorate (Nyangoko et al., 2022; Yamamoto, 2023; Dulyakasem et al., 2026).

After normalization, Q38 and Q39 were combined using their geometric mean to obtain D_E→H. The geometric mean was selected because the composite is intended to be noncompensatory: a high score on one dimension should not fully offset a low score on the other. Thus, high ecosystem-to-human dependence is indicated when households both rely strongly on mangrove-related resources and anticipate substantial livelihood consequences from ecosystem deterioration. The two component indicators were also retained separately in descriptive reporting to preserve their distinct empirical meanings. D_E→H therefore represents the empirically measured household-dependence component of the broader SESVIME coupling concept; the reciprocal human-to-ecosystem pressure or stewardship component was not independently measured in this study.

The additive household vulnerability benchmark defined in Equation (2) was used only as a diagnostic comparator and not as a SESVIME score. Its correspondence with respondents' ordered self-perceived vulnerability (Q63) was assessed using Spearman rank correlation because the outcome was ordinal and did not require assumptions of normality or interval-scale measurement. Spearman correlations were also used to examine associations among exposure, sensitivity, dependence, and adaptive capacity.

Differences between Muncar and Tegaldlimo were examined using two-sided Mann–Whitney U tests because of the modest and unequal group sizes (n = 37 and n = 19) and the ordinal basis of several household indicators. Holm-adjusted p-values were applied across the five construct-level comparisons to reduce the risk of Type I error from multiple testing, and rank-biserial correlation was

reported as an effect-size measure. These subdistrict comparisons were interpreted as exploratory rather than as population-level estimates.

Open-ended responses were summarized using keyword-assisted, multi-label thematic coding to provide contextual support for the quantitative findings. Because no independent double-coding was conducted, these responses were used only as descriptive evidence and were not treated as a standalone qualitative analysis. All statistical analyses were conducted at the household level.

Table 2. Operationalization and Descriptive Properties of the Household SESVIME Module

Construct	Survey Items/Operationalization	Cronbach alpha	Mean	SD	95% CI
Perceived exposure (E_H)	Mean of Q34-Q37, normalized 0-1	0.694	0.712	0.262	0.642-0.782
Household sensitivity (S_H)	Mean of Q44-Q48, normalized 0-1	0.777	0.766	0.237	0.703-0.830
Adaptive capacity (AC_H)	Mean of Q58-Q62, normalized 0-1	0.650	0.671	0.225	0.610-0.731
Ecosystem-to-human dependence (D_E->H)	Geometric mean of normalized Q38 and Q39	-	0.751	0.199	0.698-0.804
Additive benchmark (V_add)	[E_H + S_H + (1 - AC_H)]/3	-	0.603	0.134	0.567-0.638

Source: Primary Data Processed (2026)

RESULT AND DISCUSSION

Ecological Recovery Coexists with Persistent Environmental Exposure

Both ecological and household evidence indicate mangrove recovery but continued livelihood exposure. In total, 43 respondents (76.8%) perceived mangrove conditions as improving during the previous five years, consistent with the documented increase in mangrove extent and Mangrove Health Index reported by Hidayah et al. (2024). Nevertheless, all respondents reported that weather or seasonal changes affected their work; 64.3% experienced tidal flooding sometimes or often, and pollution (44.6%) and extreme weather (42.9%) were the most frequently identified environmental threats. Mean perceived exposure was 0.712 (SD = 0.262) and was positively correlated with household sensitivity ($\rho = 0.538$; $p < 0.001$) and ecosystem dependence ($\rho = 0.387$; $p = 0.003$).

This coexistence of ecological improvement and persistent household exposure is consistent with evidence that mangrove restoration cannot be evaluated solely through biophysical outcomes. Socioeconomic conditions influence coastal vulnerability and restoration priorities (Sagala et al., 2024), while restoration outcomes also depend on livelihood incentives, institutions, and community participation (Ebeler et al., 2025).

Livelihood Dependence Is a Major Transmission Pathway

Dependence on coastal and mangrove resources remained high. Overall, 39 respondents (69.6%) reported high or very high dependence; 87.5% expected household income to be disrupted if mangrove conditions deteriorated; 94.6% experienced environment- or weather-related income

declines; and 91.1% characterized household income as seasonal. The ecosystem-to-human dependence score averaged 0.751 (SD = 0.199) and was positively associated with household sensitivity ($\rho = 0.577$; $p < 0.001$). However, this dependence should be interpreted as dependence on the broader coastal–mangrove livelihood system rather than as direct dependence on mangrove resources alone. The respondent sample included capture fishers, aquaculture or pond farmers, and households engaged in other occupations, and the survey did not disaggregate the dependence score into separate contributions from capture fisheries, aquaculture, direct mangrove use, or other coastal activities. Accordingly, the observed association indicates a potential pathway linking coastal–mangrove resource dependence with household sensitivity, but does not establish which livelihood sector contributes most strongly to that relationship.

Income-source multiplicity should also be distinguished from livelihood diversification that effectively reduces risk. Although 82.1% of respondents reported more than one major income source, 57.1% considered switching occupations difficult or very difficult when coastal earnings declined. The survey did not quantify the relative contribution or risk covariance of individual income sources; therefore, multiple income sources cannot be interpreted as evidence of effective risk-reducing diversification. Empirical studies show that fisheries-dependent households may maintain alternative income streams while remaining exposed to ecosystem and environmental change, whereas broader livelihood alternatives can provide different adaptive opportunities (Yamamoto, 2023; Dulyakasem et al., 2026). The present findings therefore support interpreting ecosystem-to-human dependence as a potential transmission pathway within the Pangpang Bay social–ecological system, without assuming that all coastal economic activities depend directly on mangroves.

Adaptive Capacity Is Collectively Strong but Unevenly Convertible into Household Security

Collective participation and environmental learning were relatively strong: 91.1% of respondents had participated in relevant training or extension, 94.6% were active in local organizations, and 71.4% had adjusted livelihood strategies in response to environmental change. However, 55.4% lacked emergency savings, 57.1% reported poor or no access to environmental, weather, or government-program information, only 37.5% considered institutional support both present and effective, and 46.4% had difficulty absorbing sudden income declines. The adaptive-capacity score averaged 0.671 (SD = 0.225), indicating that adaptive capacity was unevenly distributed across social, informational, institutional, and financial dimensions.

This pattern is consistent with international evidence showing that community participation alone does not guarantee household resilience. In Vietnam, Ebeler et al. (2025) found that mangrove restoration could improve livelihoods and social cohesion while governance constraints, unequal benefit distribution, and market limitations continued to restrict resilience. Similarly, Du et al. (2025) showed in Quanzhou Bay that sustainable mangrove management depends on interactions among ecological conditions, stakeholder collaboration, and institutional arrangements. Pangpang Bay therefore suggests that the principal constraint is not simply weak participation, but the incomplete

conversion of collective and organizational capacity into household-level financial security, livelihood flexibility, and access to timely information.

Pangpang Bay adds an important household-level dimension to these studies. Strong participation and environmental knowledge appear to generate collective adaptive capacity, but collective capacity alone does not guarantee financial buffering or livelihood flexibility. The critical constraint is therefore not simply a lack of community participation, but the incomplete conversion of social and organizational resources into household economic security. This distinction is important for restoration policy because additional training or organizational activities may produce limited vulnerability reduction unless accompanied by improved access to savings, information, diversified livelihood opportunities, and effective institutional support.

Exploratory Subdistrict Differences and the Additive Vulnerability Benchmark

Muncar and Tegaldlimo showed broadly similar levels of perceived exposure, household sensitivity, ecosystem dependence, and additive vulnerability (Table 3). The largest unadjusted difference occurred in adaptive capacity, which averaged 0.719 in Muncar and 0.576 in Tegaldlimo (Mann–Whitney $p = 0.045$; rank-biserial $r = 0.329$). However, this difference was not statistically significant after Holm correction for multiple comparisons (adjusted $p = 0.226$), and none of the corrected subdistrict comparisons reached statistical significance. The observed adaptive-capacity contrast should therefore be treated as an exploratory pattern rather than evidence of a systematic difference between Muncar and Tegaldlimo. Potential variation in adaptive capacity may reflect differences in access to information, training, local organizations, financial buffers, livelihood flexibility, and institutional support, all of which influence households' ability to anticipate and respond to livelihood disturbances (Cinner et al., 2018). Nevertheless, the present sample was not sufficiently powered to determine which of these factors explains the observed subdistrict pattern, and this should be tested using larger and more balanced samples.

Table 3. Household Vulnerability Constructs by Subdistrict

Construct	Muncar mean (SD) n = 37	Tegaldlimo mean (SD) n = 19	Mann-Whitney p	Holm-adjusted p	Rank-biserial r
Perceived exposure	0.747 (0.264)	0.645 (0.253)	0.192	0.576	0.212
Sensitivity	0.778 (0.235)	0.742 (0.247)	0.573	1.000	0.092
Adaptive capacity	0.719 (0.203)	0.576 (0.240)	0.045	0.226	0.329
Dependence	0.776 (0.189)	0.701 (0.214)	0.127	0.506	0.246
Additive vulnerability	0.602 (0.134)	0.604 (0.139)	0.828	1.000	0.037

Source: Primary Data Processed (2026)

The diagnostic additive vulnerability benchmark averaged 0.603 (SD = 0.134; 95% CI = 0.567–0.638) and showed no association with respondents' self-perceived vulnerability ($\rho = -0.016$; $p = 0.910$). This near-zero association should be interpreted cautiously. It does not demonstrate that the two measures necessarily represent fundamentally different constructs, because the result may also reflect the modest sample size, the ordinal nature of the self-perceived vulnerability measure, and differences in how objective indicators and subjective assessments capture household experience.

Rather, the finding indicates limited correspondence between the additive benchmark and self-perceived vulnerability in this sample. This result supports further evaluation of relational and noncompensatory vulnerability formulations, but does not by itself validate SESVIME or invalidate conventional additive approaches.

Preferences for Conservation Incentives and Institutional Delivery

Respondents expressed strong support for linking mangrove conservation with livelihood and institutional incentives. All respondents supported incentives for mangrove stewards; 89.3% preferred community, fisher, or mangrove-management groups as recipients, and productive-business assistance was the most preferred single incentive form (35.7%). In addition, 75.0% expressed willingness to contribute financially to mangrove conservation and 85.7% stated that they would continue participating if the program were successful and transparent. These findings indicate stated preferences for community-based delivery, livelihood-oriented support, and transparent program implementation, but they should not be interpreted as evidence that such incentives are already effective in improving household resilience.

Previous studies suggest that conservation finance and payment-for-ecosystem-services schemes are strongly influenced by institutional credibility, benefit distribution, and local participation (Fauziyah et al., 2023; Rakotomahazo et al., 2023). In Pangpang Bay, productive-business assistance and community-based recipients represent locally preferred design options rather than demonstrated resilience interventions. Their potential contribution to livelihood resilience would need to be evaluated through implementation data, including participation, benefit distribution, income effects, and changes in household coping capacity over time.

Implications and Limitations for Full SESVIME Validation

The findings suggest that mangrove restoration should be evaluated using both ecological and livelihood indicators to determine whether ecological gains are translated into household resilience. However, this study remains exploratory. The household sample was small, geographically unbalanced, and predominantly male, limiting representativeness and gender analysis. The cross-sectional design does not establish causal effects of restoration; moreover, ecological sensitivity, ecological adaptive capacity, and human-to-ecosystem pressure or stewardship were not measured at household-compatible spatial units. In addition, ecological monitoring ended in 2023, whereas the household survey was conducted in 2026. Future SESVIME validation should therefore align ecological and household observations spatially and temporally, test alternative aggregation functions, and evaluate the framework against independent livelihood and ecological outcomes before it is used for comparative ranking or policy targeting.

CONCLUSION AND SUGGESTION

Conclusion

Ecological recovery in Pangpang Bay has not been accompanied by a comparable reduction in household livelihood vulnerability. Mangrove condition improved, yet many households remained

strongly dependent on the broader coastal–mangrove livelihood system and continued to face seasonal income, environmental exposure, limited livelihood flexibility, and uneven access to financial, informational, and institutional resources. These findings indicate that ecological restoration alone should not be assumed to improve the economic resilience of coastal households.

The study further shows that coastal–mangrove resource dependence is associated with household sensitivity and may represent a pathway through which environmental change affects livelihood security. However, this relationship should be interpreted cautiously because the cross-sectional design does not establish causality. The additive vulnerability benchmark also showed limited correspondence with self-perceived vulnerability, suggesting that household vulnerability should not be interpreted solely through a compensatory aggregate score. Overall, the findings emphasize three management priorities: maintaining ecological recovery, reducing excessive livelihood dependence and seasonal income insecurity, and strengthening household adaptive capacity through improved livelihood options, information access, financial buffers, and institutional support.

Suggestion

Mangrove management in Pangpang Bay should integrate ecological restoration with livelihood-oriented interventions for fishing and aquaculture households. Priority actions include expanding viable alternative livelihood opportunities, strengthening fisher and aquaculture organizations, improving access to timely weather and climate information, and facilitating financial and institutional support that can help households respond to income and environmental shocks.

Conservation incentives, including productive-business assistance and community-based delivery mechanisms, may be considered because they were strongly preferred by respondents; however, their effectiveness in improving livelihood resilience has not yet been demonstrated and should be evaluated before wider implementation. Future research should use larger and more balanced samples, spatially and temporally matched ecological and household data, and longitudinal designs to test whether ecological recovery is followed by measurable improvements in livelihood security and adaptive capacity.

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