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Green Finance as a Structural Driver of Small-Scale Fisheries Sustainability: A RAPFISH-Based Multidimensional Analysis

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Abstract: Small-scale fisheries are vital for coastal livelihoods and food security but face persistent sustainability challenges driven by environmental degradation, climate variability, and structural economic vulnerability. Although sustainability assessments of small-scale fisheries are well established, financial aspects—particularly green finance—are often treated as secondary or mediating factors and remain weakly operationalized within integrated analytical frameworks. This study assesses the sustainability status of small-scale fisheries and identifies key leverage attributes by explicitly embedding green finance-related attributes as cross-cutting drivers within a multidimensional sustainability assessment. Using Multidimensional Scaling (MDS) implemented through the Rapid Appraisal for Fisheries (RAPFISH) framework, sustainability was evaluated across six interrelated dimensions: economic, social, institutional, regulatory, environmental, and cultural. The analysis was applied to coastal small-scale fisheries systems in East Java Province, Indonesia, using ordinal scores derived from expert judgment and stakeholder input. Results show that the cultural dimension exhibits strong sustainability and the social dimension remains moderately stable, while economic and environmental dimensions remain highly vulnerable. Leverage analysis indicates that green finance-related attributes—particularly access to finance, financial intermediation capacity, and policy integration—emerged as high-leverage attributes the overall sustainability configuration despite their limited current implementation. These findings indicate that finance functions as a high-leverage, cross-cutting structural driver in small-scale fisheries sustainability rather than a peripheral factor, offering evidence-based insights for policy alignment, institutional coordination, and targeted financial interventions to strengthen the sustainability of small-scale fisheries.

Keywords: Small-scale fisheries; Sustainability assessment; Green finance; Financial inclusion, Rapid Appraisal for Fisheries

1. Introduction

Marine and fisheries resources are widely recognized as central to the global blue economy, supporting food security, employment, and livelihoods across coastal and island regions. An estimated 600 million people worldwide depend on marine-based economic activities; however, increasing pressures from overexploitation, marine pollution, and climate change have raised serious concerns about the long-term viability of fisheries systems and the achievement of Sustainable Development Goal 14 (Life Below Water) (Mou & Liu, 2025; Ray Biswas & Rahman, 2023; Siddique et al., 2023) These challenges are particularly pronounced in archipelagic and coastal countries, where marine resources play a dominant role in economic development. Indonesia, the world's largest archipelagic state, with a coastline of more than 95,000 km and marine areas covering nearly two-thirds of its territory, illustrates this dual condition of opportunity and vulnerability (Suherman et al., 2025). Although the fisheries sector contributes substantially to regional economies, especially in fisheries-dependent provinces such as East Java, declining catch productivity over the past decade indicates mounting sustainability pressures on small-scale fisheries driven by unsustainable exploitation practices. These challenges—financial fragility, fragmented governance, and uneven sustainability outcomes—are not unique to Indonesia but echo structural constraints documented in small-scale fisheries worldwide. Comparative and international scholarship shows that financial exclusion, weak co-management, and the limited integration of social and financial dimensions recurrently constrain the contribution of small-scale fisheries to the Sustainable Development Goals across diverse settings (Bitoun et al., 2024; Scheld et al., 2024; Smallhorn-West et al., 2022). Situating the East Java case within this broader debate clarifies which pressures reflect globally shared vulnerabilities and which are context-specific, thereby strengthening the wider relevance of the present analysis. Beyond these largely qualitative accounts, recent remote-sensing approaches enable quantitative, spatially explicit monitoring of the atmospheric and industrial pressures affecting coastal ecosystems: satellite platforms such as Sentinel-5P have been used to characterize coastal air quality and combustion-related pollutant burdens (Lacey et al., 2026), while related work links greenhouse-gas and methane management to climate action toward net-zero targets (Ghahremanlou & Ghahremanlou, 2025). Integrating such evidence connects the environmental dimension of small-scale fisheries sustainability to measurable indicators of emission management and coastal environmental quality.

Escalating resource exploitation and growing climate instability have intensified pressures on fisheries systems worldwide, with particularly severe consequences for small-scale fisheries that depend on localized ecosystems and limited adaptive capacity. Declining fish stocks, habitat degradation, and climate-driven variability in ocean conditions have reduced catch predictability and increased livelihood risks for small-scale fishers, reinforcing patterns of economic vulnerability and structural poverty (Efani et al., 2025; Novira et al., 2024; van Noordwijk, 2019). In response, global regulatory and policy frameworks such as the Food and Agriculture Organization of the United Nations (FAO) Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries, Sustainable Development Goal 14 (notably Target 14.b), and the United Nations Convention on the Law of the Sea (OJK, 2017; United Nations, 1982; United Nations, 2015) have articulated principles of sustainable resource use, equitable access, and improved livelihoods for small-scale fishing communities. Nevertheless, these frameworks primarily emphasize conservation objectives and governance norms, while offering limited guidance on how small-scale fishers can practically absorb the economic risks associated with sustainability transitions amid climate uncertainty. Consequently, regulatory measures intended to curb overexploitation may inadvertently shift the costs of sustainability, such as reduced fishing effort, compliance burdens, or restricted access for small-scale fishers in the absence of adequate financial support, risk-sharing mechanisms, or adaptive capacity-building measures (Boldt et al., 2023; Engle & van Senten, 2022).

Climate-related pressures, including increasing weather extremes and seasonal uncertainty, have intensified the vulnerability of small-scale fishers by disrupting fishing operations, reducing effective fishing time, and increasing income instability. This strong dependence on environmental conditions creates recurrent and predictable livelihood crises, particularly during seasonal lean periods, which are often managed through informal coping strategies (Alawode, 2025; Ema et al., 2025). Limited access to formal finance under these conditions has enabled the expansion of informal and frequently predatory financing arrangements, commonly dominated by intermediaries who impose tied transactions and monopsonistic pricing practices that depress incomes and reinforce chronic indebtedness (Nugroho et al., 2025). At the same time, a persistent gap between national blue economy ambitions and the socio-economic realities of coastal communities persists, as large-scale maritime development proceeds without adequately addressing the financial fragility of small-scale fisheries, thereby constraining their capacity to invest in sustainable practices and escape poverty traps amid increasing climate risk.

Despite the growing prominence of green finance within sustainable development agendas, its application in small-scale fisheries and coastal development remains conceptually fragmented and empirically underexplored. More fundamentally, green finance remains weakly operationalized within fisheries sustainability assessments: it is rarely treated as an explicit, measurable component of multidimensional sustainability frameworks and is instead positioned as an external or mediating consideration. This weak operationalization—rather than the limited access to finance and the blue economy gap that are among its symptoms—constitutes the central research gap addressed by this study. Existing studies highlight the importance of regulatory frameworks (Bova et al., 2025; Standal & Ahlquist, 2025), economic incentives (Bertelsen et al., 2025), technological readiness, and local capacity in shaping sustainability outcomes (Hungevu et al., 2025; Khaskheli et al., 2025; Satyro et al., 2024); however, these factors are often examined in isolation, without sufficient attention to their contextual interactions across economic, social, institutional, regulatory, environmental, and cultural dimensions. In practice, weak coordination among actors and persistent policy fragmentation, where environmental objectives and financial policies operate in parallel rather than in an integrated manner, limit the effectiveness of green finance in addressing the structural vulnerabilities of small-scale fisheries. Moreover, while ecological approaches and blue economy frameworks have received considerable scholarly attention, green finance has largely been applied outside the fisheries sector (Jiang et al., 2025; Wang & Xu, 2025) predominantly in energy and transport (Hanif & Zheng, 2025; Raman et al., 2025) and is frequently treated as a mediating or supporting variable rather than a structural driver of economic resilience and environmental quality (Neger et al., 2025). Unlike previous fisheries sustainability studies that treat financial variables as secondary or mediating factors, this study explicitly embeds green finance-related attributes across multiple sustainability dimensions and empirically tests their leverage effects within the overall sustainability configuration. To address this gap, this study is guided by two research questions: (1) What is the multidimensional sustainability status of coastal small-scale fisheries in East Java across the economic, social, institutional, regulatory, environmental, and cultural dimensions? and (2) which green finance-related attributes function as key leverage points shaping the overall sustainability configuration of these systems? Accordingly, this study applies Multidimensional Scaling (MDS) across six interrelated dimensions—economic, social, institutional, regulatory, environmental, and cultural—to identify key leverage attributes through which green finance influences the sustainability configuration of small-scale fisheries systems, providing an integrated and empirically grounded basis for policy alignment, institutional coordination, and targeted financial interventions in coastal fisheries development.

2. Methodology

2.1 Research Location

This study was conducted in selected coastal areas of East Java Province, Indonesia, which represent key small-scale fisheries systems characterized by high socio-economic dependence on marine resources and increasing environmental and climate-related pressures. East Java is one of Indonesia's major fisheries-producing regions, with a diverse range of capture fisheries activities dominated by small-scale fishers operating in nearshore waters. The province also exhibits pronounced contrasts between economic contribution and livelihood vulnerability, making it a relevant case for examining sustainability challenges and the role of green finance in coastal fisheries development. The spatial distribution of the selected study sites in East Java Province is presented in Figure 1.

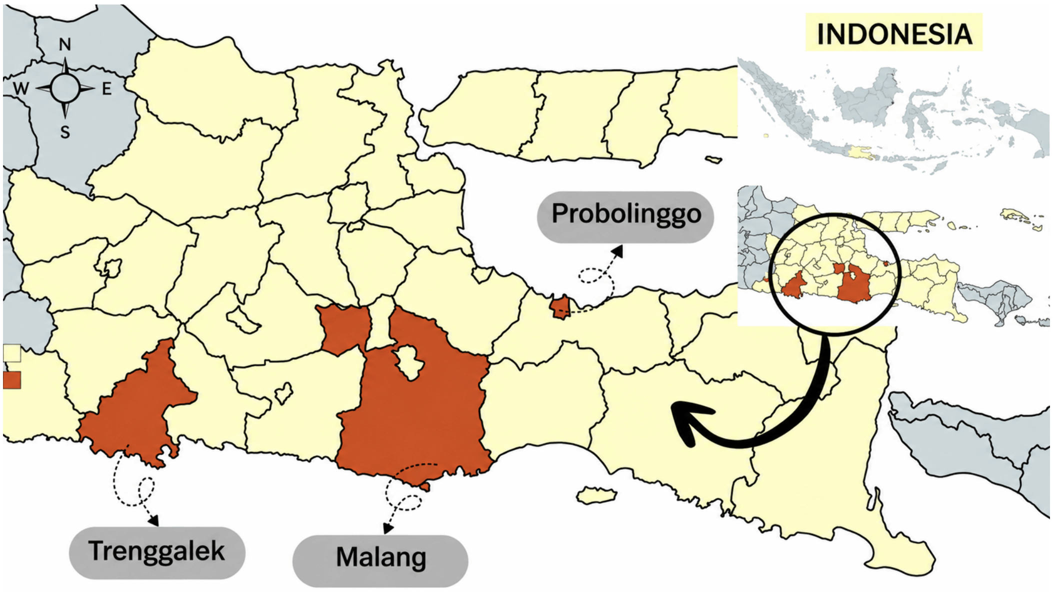

Figure 1. Research location

Three coastal sites were purposively selected to capture variations in fisheries characteristics and institutional contexts: Sendang Biru (South Malang Regency), Prigi (Trenggalek Regency), and Mayangan (Probolinggo City). These locations represent different coastal typologies—southern and northern coasts, rural and urban settings, and varying levels of institutional and market access—while maintaining a common focus on small-scale fisheries. This diversity supports a comparative application of the MDS approach and enhances the broader relevance of the findings for small-scale fisheries sustainability.

2.2 Population and Sample

The population of this study consists of key stakeholders involved in small-scale fisheries systems in selected coastal areas of East Java Province, Indonesia, including Sendang Biru (South Malang Regency), Prigi (Trenggalek Regency), and Mayangan (Probolinggo City). These stakeholders possess direct knowledge of fisheries activities, resource conditions, institutional arrangements, and access to finance within the study areas. A purposive sampling approach was applied to select respondents with relevant experience and expertise, consistent with multidimensional sustainability assessments using MDS (Campbell et al., 2020; Etikan, 2016). The sample included small-scale fishers, representatives of fisher groups or cooperatives, local government officials, financial or institutional actors, and fisheries experts. Data were collected through structured interviews and expert judgment to assign ordinal scores to sustainability attributes, with triangulation across respondent groups to ensure robustness. The sample included a total of 24 respondents, comprising small-scale fishers (n = 6), representatives of fisher groups or cooperatives (n = 6), local government officials (n = 3), financial or institutional actors (n = 3), and fisheries experts (n = 6). The distribution of respondents across the three study sites was structured as follows: Sendang Biru (n = 8), Prigi (n = 8), and Mayangan (n = 8). This sample size is consistent with previous Rapid Appraisal for Fisheries (RAPFISH)-based sustainability assessments, which prioritize informed expert judgment and stakeholder knowledge over statistical representativeness because the objective is to generate reliable ordinal attribute scores for multidimensional sustainability evaluation rather than to estimate population parameters. Data were collected through structured interviews and expert judgment to assign ordinal scores to sustainability attributes, with triangulation across respondent groups to ensure robustness.

2.3 Operationalization and Dimensional Allocation of Green Finance

This study treats green finance not as a single variable but as a mechanism that cuts across the fisheries finance system. Following (Taghizadeh-Hesary & Yoshino, 2019) green finance is defined here as formal financial instruments and services designed or adapted to support environmentally sustainable practices, climate resilience, and resource conservation among small-scale fishers.

To reduce the risk that respondents interpret "green" differently depending on which instrument comes to mind, the definition was operationalized around four instrument types that were explained to respondents during the questionnaire briefing: sustainability-linked micro-credit (loans with terms tied to environmental performance, such as gear certification or catch reporting compliance), climate-adaptation loans (financing for adaptive measures like alternative fishing seasons or storm-resistant equipment), subsidized financing for eco-friendly fishing gear (e.g., selective nets or biodegradable materials), and blue bond-linked or sustainability-certified credit schemes where available at the port level. Respondents were shown these four categories with local examples before answering items under each dimension, so that "green finance" referred to the same underlying set of instruments regardless of which dimension the item was measuring.

Because the concept operates at several levels of the system at once, its attributes were allocated across three dimensions rather than folded into a single indicator. This allocation follows a supply–demand–enabling environment logic that is well established in the financial inclusion literature: access captures whether an instrument is available and used (Pesqué-Cela et al., 2021; Yorulmaz, 2018) literacy or awareness captures whether the user has the capability to engage with it, and macro-level policy captures whether the regulatory environment mandates or incentivizes its provision. ElDeeb et al., (2021) tested this separation empirically for small and medium-sized enterprise (SME) financial inclusion in Egypt using principal component analysis, and found that access, usage, and macroeconomic-policy determinants load onto three distinct components, together explaining 86.6% of variance without meaningful cross-loading. This gives the three-way split used here an empirical basis rather than treating it as a convenient theoretical partition.

Concretely, the economic dimension, access to green finance, measures the availability of the four instrument types above and their uptake by fishing households, drawing on indicators adapted from access-side financial inclusion metrics (Jellouli et al., 2026). The social dimension, green finance literacy, measures whether fishers understand these specific instruments well enough to use them, a gap (Pomeroy et al., 2020) identify as a primary barrier to financial inclusion among small-scale fishing households in developing countries; items here ask about comprehension of loan terms and eligibility rather than about availability, so a fisher can score high on literacy while still lacking access, or vice versa. The regulatory dimension, ESG policy integration and green incentive policy, measures the institutional frameworks that mandate or encourage green finance provision at the macro level, anchored in Indonesia's POJK 51/2017 on Sustainable Finance (OJK, 2017) items here address policy awareness and institutional presence at the port and district level, not individual instrument use.

To check that this conceptual separation held in the data rather than just on paper, bivariate correlations between the access, literacy, and regulatory indicators were examined prior to MDS ordination, and none exceeded the threshold typically used to flag redundant indicators in RAPFISH-type analyses. The MDS ordination within the RAPFISH framework (Pitcher & Preikshot, 2001) then treats each dimension independently, and leverage diagnostics were used to confirm that no single green-finance-related attribute was driving the ordination on its own within more than one dimension. This combination of a priori definitional boundaries, literature-grounded dimensional separation, and post hoc correlation checks is what keeps the distributed allocation of green finance attributes from introducing collinearity or double-counting into the sustainability indices.

2.4 Data Collection and Scoring Procedure

Data were collected from primary and secondary sources. Primary data were obtained through structured interviews and expert judgment involving key stakeholders in small-scale fisheries between September and December 2025. It is important to note that this temporal window coincides with the transitional weather period (*pancaroba*) leading into the wet season in East Java. During these months, small-scale fishers typically experience fluctuating weather conditions and localized high waves, which can temporarily restrict fishing days and exacerbate economic vulnerability, thereby contextualizing the conservative scores in the economic and environmental dimensions. Secondary data were drawn from official statistics, policy documents, and relevant literature. Data triangulation was applied to improve the reliability of the assessment. To ensure that different respondents interpreted the same attributes consistently, detailed scoring rubrics based on the operational definitions were provided prior to the assessment. Furthermore, to mitigate anchoring effects and groupthink, scores were initially collected independently from each stakeholder before being aggregated and discussed. Inter-rater reliability was implicitly monitored during this triangulation phase to address extreme divergence in subjective inputs. In instances where significant score discrepancies emerged between different stakeholder groups (e.g., an expert assigning a high score while a fisher assigned a low score), the divergence was resolved through a facilitated group consensus discussion rather than simple arithmetic averaging or differential weighting. Because scores were initially collected separately, all stakeholder groups were assigned equal weight to prevent marginalizing fisher perspectives. Consequently, subgroup statistical comparisons were not conducted, as the final MDS inputs were derived from the reconciled post-discussion consensus. This consensus-building process allowed stakeholders to contextualize their judgments and agree upon a representative ordinal value. Each sustainability attribute was assessed using an ordinal scoring scale (0–4), a well-established approach in RAPFISH methodologies to quantify multidimensional qualitative data (Pitcher & Preikshot, 2001; Ramadona et al., 2020) For this scale, 0 indicates very poor or non-existent conditions, 1 indicates limited condition, 2 indicates moderate conditions, 3 indicates good conditions, and 4 indicates very good conditions (Frederiksen et al., 1996). The operational definitions for each attribute are presented in Table 1, which served as the main reference to ensure consistency and comparability across respondents and study sites. The resulting scores were used as input for the MDS analysis.

Table 1. The operational definitions

Dimension	Attribute	Description
Economic	Access to green finance	The degree to which small-scale fishers can access formal green or sustainability-oriented financial instruments (e.g., green credit, concessional loans).
	Income stability	The extent to which fishing household income remains stable across seasons and climate variability.
	Cost efficiency	Ability to reduce production costs through efficient input use, technology, or financing mechanisms.
	Value added retention	Proportion of fisheries value retained at the local/community level rather than captured by intermediaries.
	Financial risk exposure	Level of vulnerability to financial shocks, debt dependency, and income loss.
Social	Green finance literacy	Level of understanding among fishers regarding green finance instruments and sustainable financial practices.
	Social inclusion	Degree of inclusion of women, youth, and marginalized groups in fisheries-related economic activities.
	Employment security	Stability and continuity of employment within small-scale fisheries livelihoods.
	Community participation	Extent of community involvement in decision-making processes related to fisheries management and finance.
	Social cohesion	Strength of trust, cooperation, and collective action within fishing communities.

Institutional	Institutional readiness	Capacity of local institutions to support sustainable fisheries and green finance implementation.
	Financial intermediation capacity	Ability of financial institutions or cooperatives to channel green finance to small-scale fishers.
	Coordination mechanism	Effectiveness of coordination among government, financial institutions, and community organizations.
	Monitoring & Accountability	Existence and effectiveness of monitoring systems and accountability mechanisms.
	Technical support services	Availability of technical assistance and advisory services related to finance and sustainability.
Regulatory	Environmental regulation	Strength and enforcement of environmental regulations governing fisheries activities.
	ESG policy integration	The degree to which ESG principles are integrated into fisheries and financial policies.
	Green incentive policy	Availability of regulatory incentives supporting environmentally responsible fisheries practices.
	Enforcement capacity	Ability of authorities to enforce fisheries and environmental regulations.
	Policy consistency	Alignment and coherence between environmental, fisheries, and financial policies.
Environmental	Fish stock condition	Status of fish stocks relative to sustainable exploitation levels.
	Habitat & Ecosystem quality	Condition of marine and coastal ecosystems supporting fisheries.
	Fishing gear selectivity	The extent to which fishing gear minimizes bycatch and ecosystem damage.
	Resource use efficiency	Efficiency in the use of natural resources and energy in fishing operations.
	Environmental pressure	Intensity of environmental stress caused by fishing activities and external factors.
Cultural	Compatibility with local practices	The degree to which sustainability and financial interventions align with local customs and traditions.
	Adaptive capacity	Ability of fishers to adjust practices in response to environmental and economic change.
	Knowledge transmission	Continuity of fisheries-related knowledge transfer across generations.
	Innovation acceptance	Willingness of fishers to adopt new technologies and sustainable practices.
	Behavioral change readiness	Readiness of individuals and communities to modify behavior toward sustainability.

Source: Compiled by the authors based on Cámara & Santero-Sánchez (2019), Imbwae et al. (2023), International Finance Corporation (2022), Squires et al. (2023), WorldFish (2020), and Xu et al. (2025).

2.5 Data Analysis

Data analysis was conducted using a MDS approach following the RAPFISH framework to evaluate the sustainability of small-scale fisheries systems. Ordinal scores were compiled into a data matrix and analyzed using the RAPFISH add-in (specifically utilizing the Rap1.xla macro and Alternating Least Squares SCALing (ALSCAL) algorithm) implemented in Microsoft Excel. Prior to ordination, the data matrix was standardized using *z*-score transformation to ensure uniformity across qualitative inputs. The MDS ordination was then executed based on

Euclidean distance (Akram & Pervaiz, 2025; Diaz & Warner, 2024). The goodness of fit of the ordination was evaluated using Kruskal's stress value and the coefficient of determination (R^2). Following ALSCAL's procedure, RSQ is computed directly as the squared correlation between the input disparities and the ordination-derived distances, rather than being algebraically derived from the stress value (e.g., as $1 - \text{Stress}^2$); the two are reported as complementary, independently calculated goodness-of-fit indicators. Robustness of the results was examined through Monte Carlo simulation utilizing 100 iterations to test for potential random errors, which inherently functions as a sensitivity analysis to assess how random variations or errors in subjective expert scoring might affect the stability of the final sustainability indices (Kavanagh & Pitcher, 2004), Furthermore, leverage analysis based on root mean square (RMS) change was applied to identify the most influential attributes affecting the sustainability configuration. Ordination scores were subsequently transformed into a RAPFISH sustainability index (0–100) using min-max normalization, scaling the scores against extreme hypothetical reference points (the best and worst possible outcomes), to support interpretation across dimensions (Hout et al., 2013). Figure 2 illustrates the analytical workflow of the MDS–RAPFISH procedure, including data preparation, ordination, goodness-of-fit assessment, robustness testing, leverage analysis, and index transformation.

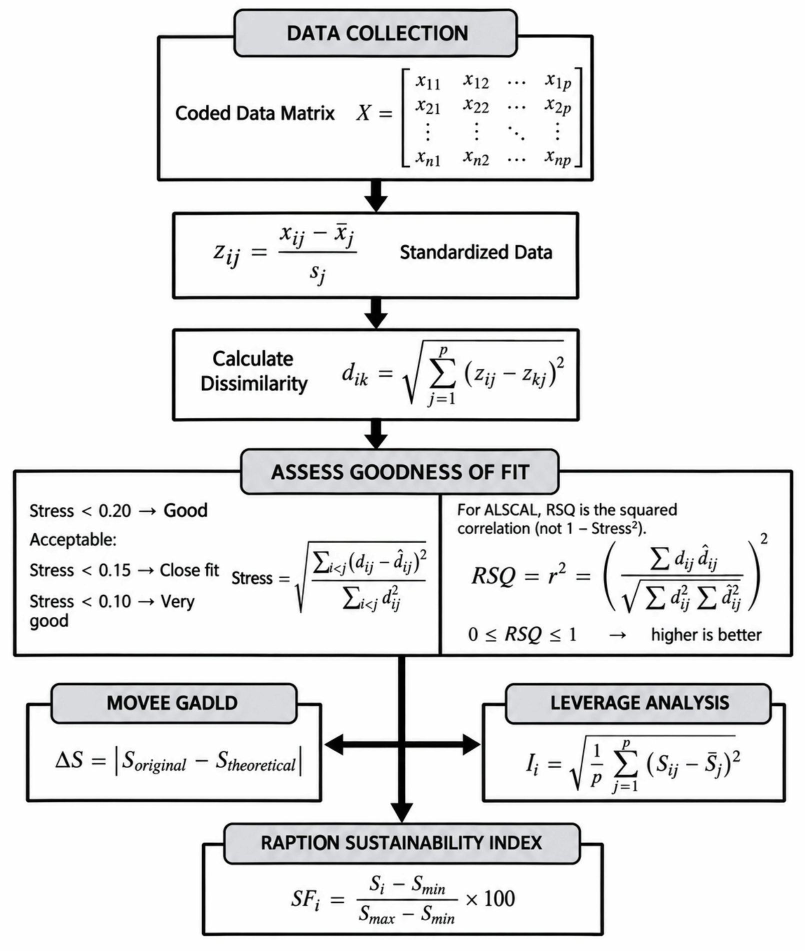

Figure 2. The analytical workflow

3. Results and Discussion

3.1 Validation Test (R^2 and Stress Value) and Monte Carlo Test

The MDS ordination for each sustainability dimension demonstrated strong model validity. All stress values fell below the recommended threshold of 0.25, ranging from approximately 0.14 to 0.17, while R^2 values exceeded 0.90 across all dimensions. For instance, the Institutional dimension recorded a stress value of 0.17 and an R^2 of 0.9296, indicating excellent goodness-of-fit (Gayat et al., 2012) These values confirm that the RAPFISH configuration reliably represents the underlying data structure with minimal distortion. Table 2 presents the complete validity test results, including R^2 and stress values for each of the six dimensions.

Table 2. Results of the Multidimensional Scaling (MDS) validation test

Sustainability Dimension	Parameters	
	R^2	Stress Value
Economic	0.9332	0.16
Social	0.9373	0.15
Institutional	0.9296	0.17
Regulatory	0.9346	0.14
Environmental	0.9340	0.16
Cultural	0.9377	0.15

Monte Carlo randomization tests were used to assess the ordination's statistical stability. Following the criteria established by Kavanagh & Pitcher (2004) and Pollnac et al. (2001), the average difference between the actual MDS sustainability index and the Monte Carlo simulation replicates remains below 5%. In this study, all six dimensions met this criterion, with differences ranging from 0.04% (social) to 1.28% (cultural), confirming that repeated random permutations did not substantially alter the sustainability configuration and supporting the robustness of the ordination results. Figure 3 displays the Monte Carlo scatterplots, illustrating the tight clustering of actual versus simulated points, and Table 3 summarizes the numerical results of the Monte Carlo test, supporting the robustness of the overall analysis.

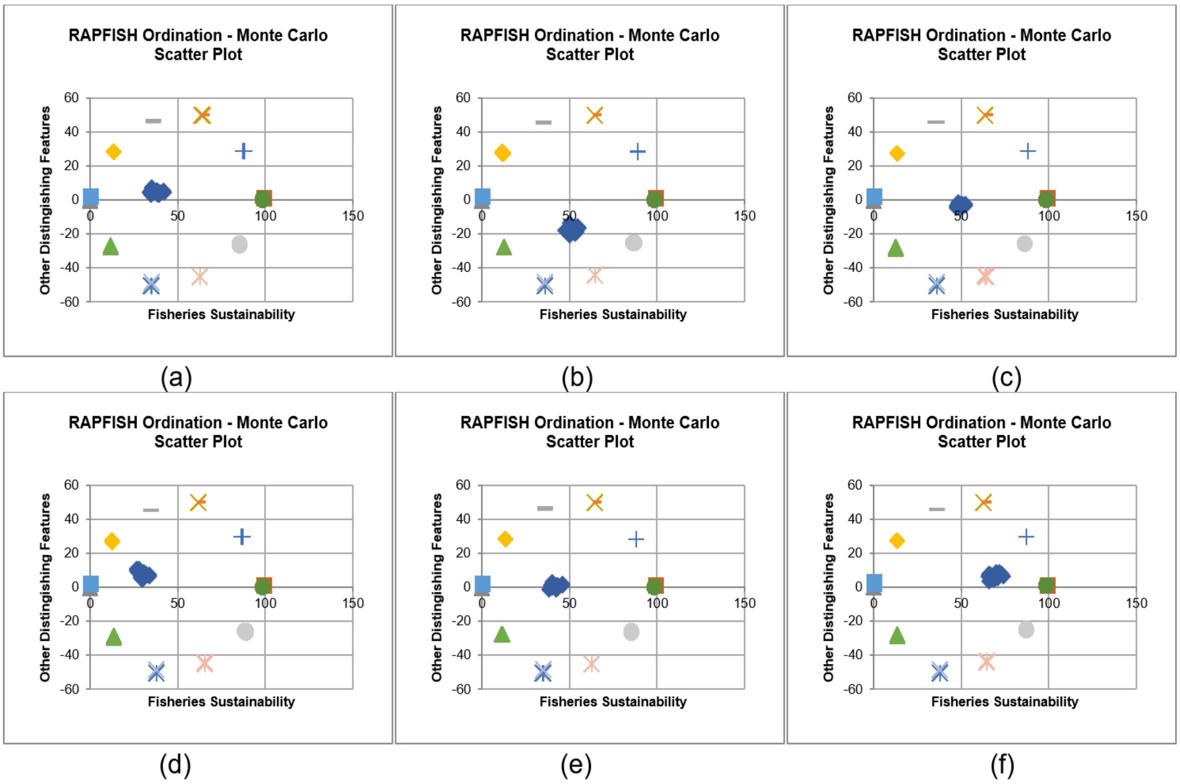

Figure 3. Monte Carlo ordinations: (a) economic; (b) social; (c) institutional; (d) regulatory; (e) environmental; (f) cultural

Table 3. Monte Carlo analysis

Sustainability Dimensions	Sustainability Index		Absolute Difference	Status
	Score Rapfish	Monte Carlo		
Economic	38.02	38.20	0.18	Less sustainable
Social	52.06	52.10	0.04	Fairly sustainable
Institutional	49.72	49.60	0.12	Less sustainable
Regulatory	38.30	39.50	1.20	Less sustainable
Environmental	42.25	42.10	0.15	Less sustainable
Cultural	70.73	69.45	1.28	Fairly sustainable

3.2 Multidimensional Sustainability Status of Small-Scale Fisheries in Coastal Areas

The RAPFISH analysis yielded a wide range of sustainability scores across the six dimensions. On a 0–100 scale, scores of 0–25 indicate "unsustainable", 26–50 "less sustainable", 51–75 "fairly sustainable", and 76–100 "sustainable" (Rizqia Ramadhanty et al., 2022). Figure 4 presents a visual comparison of the sustainability indices for all six dimensions—economic, social, institutional, regulatory, environmental, and cultural—highlighting both strengths and areas of critical concern.

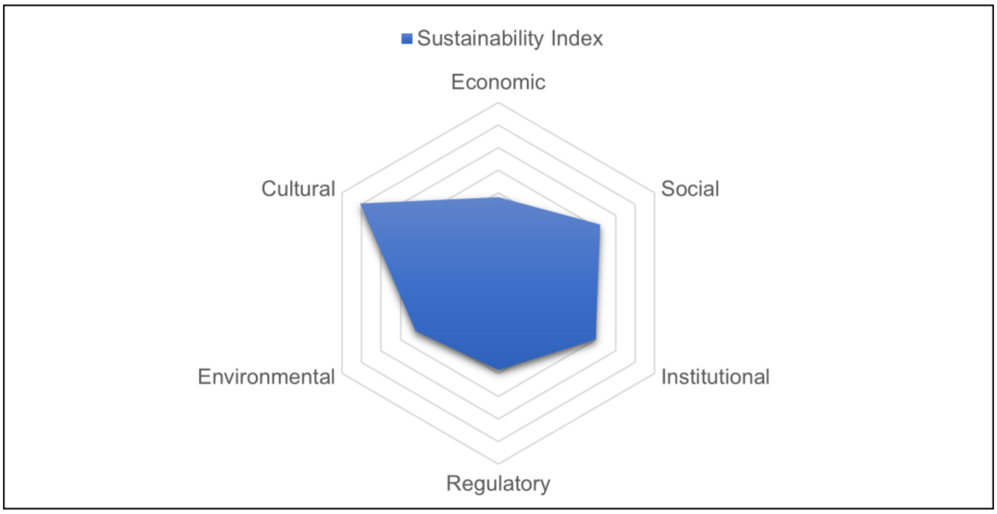

Figure 4. Sustainability index

The cultural dimension scored highest (70.73%), falling solidly in the fairly sustainable category. This reflects strong alignment with local traditions, knowledge transmission, and adaptive practices. In contrast, the economic, regulatory, and environmental dimensions scored below 45% (in the "less sustainable" range). For example, the Economic index (38.02%) reflects very low values in income stability, cost efficiency and green-finance access, indicating chronic livelihood precarity. The environmental index (42.25%) similarly signals degraded stocks and habitat quality (low ratings on resource use efficiency and high pressures). By comparison, the social index (52.06%) was in the "fairly sustainable" range, while the institutional dimension scored (49.72%) "less sustainable". Notably, the social dimension's index mirrors findings by Susilo et al. (2021), who reported insufficient overall sustainability (47.6%) but found social capital to be the most resilient component in East Java. Similarly, Jakarta Bay fisheries post-reclamation scored only approximately 46%–50% on social sustainability (Patawari et al., 2022). Overall, our results underscore a pattern seen elsewhere in small-scale fisheries: strong community cohesion and cultural capital (which bolster social resilience) coexist with weak economic and ecological health. The striking gap between high cultural/social scores and low economic/environmental scores highlights a multidimensional trade-off. In particular, the very low score for access to green finance in the economic dimension and environmental pressure in the environmental dimension dragged down those indices. These findings align with global assessments indicating that small-scale fisheries often exhibit robust traditional knowledge but face market and resource pressures.

3.3 Leverage Analysis of Sustainability Attributes in Small-Scale Fisheries

Leverage analysis expressed through RMS values identified the attributes whose change would most strongly shift the sustainability indices. It is crucial to distinguish between an attribute's current baseline score and its RMS value: a high RMS value indicates that the overall system configuration is highly sensitive to that specific attribute, regardless of whether its current baseline score is high or low. Therefore, this analysis does not merely restate weak attribute performance but identifies analytically meaningful structural drivers. Table 4 displays the RMS values for each attribute, highlighting the highest-sensitivity values within each dimension. These leverage attributes represent critical intervention points, where improvements would disproportionately enhance overall sustainability performance.

In the economic dimension, the most sensitive attribute was financial risk exposure (RMS = 4.34), followed by access to green finance (RMS = 2.12) and income stability (RMS = 1.84). This indicates that the economic index is most acutely shaped by fishing households' vulnerability to financial shocks and debt dependency, alongside their limited access to formal green financing and unstable income. Improvements in these areas for instance, through risk-sharing mechanisms, diversified livelihoods, or better market access would substantially raise the economic index. The social dimension revealed green finance literacy (score 0/4) as a key leverage point—fishers' lack of awareness of sustainable financing options is dragging down overall social sustainability. This resonates with global observations that small-scale fisheries are often trapped in poverty due to a lack of formal financial services. For instance, underinvestment in credit and insurance forces communities into exploitative lending, exacerbating vulnerability. In the institutional dimension, financial intermediation capacity and coordination mechanisms scored only 1/4, indicating that weak institutional support systems (banks, cooperatives, and cross-sectoral coordination) are limiting sustainability. The regulatory dimension's leverage attributes were most stark: ESG policy integration and green incentive policies both scored 0/4. Their absence makes the regulatory framework a bottleneck. Strengthening these policies—for example, by formalizing subsidies for eco-friendly gear or mandating environmental impact assessments—would likely produce large gains. The environmental dimension showed resource use efficiency (RMS = 4.63) and environmental pressure (RMS = 2.93) as highly leveraged, while environmental pressure currently suffers from a low baseline condition, its high leverage indicates that the broader ecological configuration is acutely sensitive to it; thus, reducing pollution and over-extraction would trigger outsized, systemic improvements rather than just isolated gains. In contrast, cultural attributes were uniformly high (scores 2–4), so no single cultural trait dominated the index; this implies cultural capital is an existing strength rather than a vulnerability. Overall, the leverage analysis highlights that attributes connected to finance (income, credit, incentives) and governance (coordination, policy integration) are "tipping points" for sustainability. This echoes Jakarta Bay findings where poverty and conflict were the most sensitive social factors, and suggests targeted interventions in these areas could yield outsized benefits.

Table 4. Leverage analysis

Sustainability Dimensions	Sensitive Attribute
Economic	Financial risk exposure (4.34) Access to green finance (2.12) Income stability (1.84)
Social	Social cohesion (6.19) Employment security (6.18) Green finance literacy (5.83)
Institutional	Coordination mechanism (2.89) Financial intermediation capacity (2.38) Monitoring & Accountability (2.29)
Regulatory	Green incentive policy (9.92) ESG policy integration (7.19) Enforcement capacity (4.4)
Environmental	Resource use efficiency (4.63) Environmental pressure (2.93) Fishing gear selectivity (0.44)
Cultural	Knowledge transmission (7.46) Compatibility with local practice (5.27) Innovation acceptance (4.85)

3.4 Interpretation of Green Finance Sensitivity Across Dimensions

A central contribution of this study is treating green finance as a cross-cutting theme rather than a standalone sector. Attributes explicitly related to green finance appeared in multiple dimensions: "access to green finance" (economic), "green finance literacy" (social), "ESG policy integration", and "green incentive policy" (regulatory). All of these scored very low or zero, revealing major gaps. Interpreted holistically, this means that financial mechanisms for conservation and sustainability are underdeveloped across the board. For instance, the absence of green finance literacy among fishers suggests they cannot effectively use even existing sustainable finance products. Likewise, the regulatory system lacks policy incentives or ESG standards to channel capital toward sustainable practices. This integrated view contrasts with how some studies have treated finance. For example, Shen & Zhang (2024) demonstrated that green finance in agriculture reduces pollution via mediating factors like land tenure reform and regulation. In our small-scale fisheries context, we instead operationalize finance within each dimension itself. Our approach aligns with FAO guidance that access to inclusive, environmentally-oriented finance should strengthen both ecological and economic viability of fisheries. The fact that green finance attributes rank highly across multiple dimensions underscores their systemic influence. It suggests that prioritizing green credit programs or fiscal incentives appears to be a key intervention area that may be associated with broader improvements in social welfare, governance capacity, and conservation outcomes. This finding resonates with blue economy finance dialogues, underscoring the need for innovative instruments (impact bonds, blended finance, microcredit) to unlock sustainable development in coastal communities.

3.5 Policy Implications

The leverage analysis shows the sustainability ordinations most sensitive to green incentive policy, ESG policy integration, and green finance literacy—the three green finance-related attributes with the highest RMS values in Table 4.

This points to a policy implication worth naming directly: financial constraints in these coastal communities look less like a simple funding shortfall and more like something structural. Since these same attributes also score poorly at baseline, expanding credit supply by itself probably won't move much. The leverage is spread across several dimensions, which is consistent with financial access depending on institutional coordination, regulatory alignment, and capacity-building for fishers and local intermediaries, not just on the amount of credit available.

What that might mean for interventions is worth stating carefully, since the leverage analysis identifies sensitivity, not solutions. Coordinating decision-making and budget processes across institutions, so green finance functions as one connected system instead of separate programs, looks like a more promising direction than what the current gaps suggest is happening now. In practice, that could mean linking subsidized microcredit to financial literacy training and environmental compliance requirements, or building coordination between local governments, regional financial institutions, and fishing cooperatives to close the gap between ESG policy as written and what's actually reachable at the port level. These are possibilities the leverage pattern is consistent with, not conclusions it proves—the analysis tells us where the model is sensitive, not which specific intervention would work. To make these implications concrete, policy responses need to line up directly with the high-leverage attributes the RAPFISH-MDS analysis identified. Some of this could realistically be piloted soon; the rest needs longer institutional reform to take hold.

Start with financial intermediation capacity. In the near term, credit officers at local cooperatives could be trained to actually read the seasonal, irregular cash flows that come with small-scale fishing, instead of applying lending criteria built for steadier income. Further out, regional development banks could open dedicated "blue-finance" windows with guarantee requirements that accept a cooperative's endorsement in place of the physical collateral most fishers don't have. Getting there would take regional development banks, local fishing cooperatives, and financial regulators working together, not any one of them acting alone.

Green finance literacy has a more immediate entry point: mobile workshops at fish auction sites (TPI) introducing basic financial recording and micro-savings directly to fishing households. What would make that stick, rather than fade after the pilot ends, is folding financial and environmental literacy into the training fisheries extension officers already deliver, so it becomes routine rather than a one-off program. That shift depends on extension officers, local non-governmental organizations (NGOs), and village governments carrying it forward together.

ESG policy integration and access to green finance are grouped together because weakness in one tends to compound the other. A workable pilot is microcredit where loan approval and subsidized rates are conditional on fishers adopting eco-friendly gear, which gives both dimensions a shared lever to move. The institutional version would be a regional Fisheries Improvement Fund pooling municipal budgets with private impact investment, so financing doesn't rest on one source that can dry up. That requires local governments, the Ministry of Marine Affairs and Fisheries, and private impact investors all being involved from the start.

Environmental pressure and resource use efficiency can start with community-led monitoring and incentives for reporting and reducing local pollution—marine debris and ghost nets especially. The longer-term step is writing resource efficiency metrics into co-management frameworks that are legally tied to marine spatial planning and operational licensing, so compliance stops being optional. That falls to fishers' associations, coastal community groups, and provincial environmental agencies to carry out.

4. Conclusions

This study highlights the critical role of green finance in shaping the sustainability of small-scale fisheries in East Java, Indonesia. Using a RAPFISH-based MDS approach across six interrelated dimensions—economic, social, institutional, regulatory, environmental, and cultural—the analysis reveals stark disparities: while cultural and social dimensions show relative strength, economic, regulatory, and environmental dimensions remain weak and vulnerable. Leverage analysis identifies green finance-related variables—such as access to finance, ESG policy integration, and financial literacy—as the most influential attributes affecting sustainability outcomes. These findings reinforce that green finance is not a peripheral mechanism but a structural leverage point indicating priority areas for multidimensional improvements.

Validation through low-stress values and high R^2 scores, supported by stable Monte Carlo simulations, confirms the model's robustness and underscores the urgency of addressing financial and institutional deficits. Addressing these deficits implies a procedural shift for policymakers; decision-making processes, inter-institutional coordination, and budgetary mechanisms must be systematically realigned to integrate financial inclusion with environmental objectives. Embedding green finance into governance systems offers a strategic pathway to enhance economic resilience, environmental recovery, and institutional effectiveness—laying the foundation for long-term sustainability in coastal fisheries and offering conditional adaptability for similar contexts worldwide, provided that local calibration is performed.

This study has real limits, and they're worth being upfront about. RAPFISH is an exploratory technique built on MDS ordination, and because its inputs are ordinal scores from expert judgment, it cannot establish causal relationships—the sustainability indices it produces are relative rankings, not absolute metrics. One fishery can be shown as more or less sustainable than another, but the numbers do not tell you how sustainable either one "really" is. There's also the standard problem with expert-driven scoring: elite bias, where a policymaker's technical priorities quietly override what fishers actually experience day to day.

Spatially, the study covers three sites in East Java, so the findings don't automatically travel beyond those ports. Temporally, the data are cross-sectional and were collected in one transitional season, which means the analysis cannot tell a structural weakness apart from ordinary seasonal swings, and it cannot speak to longer-term trends at all. Two things would help. Longitudinal or repeated cross-sectional studies would capture seasonal variation and give later work an actual baseline to measure change against. And pairing RAPFISH's exploratory scoring with a confirmatory method—structural equation modeling (SEM), or a quasi-experimental design—would let researchers test whether green finance interventions actually cause the sustainability outcomes this study can only describe as correlated. Future research could also test the cross-dimensional allocation logic of green finance attributes using confirmatory factor analysis across different geographic and institutional settings.

Author Contributions

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

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Data Availability

Data used to support the findings of this study are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflicts of interest.

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