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Structural sustainability imbalances in community-managed mangrove ecosystems in Central Java, Indonesia

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Abstract. *Iftitani MA, Dewi MPS, Sheliana MS, Hapsari M, Wahyuni T, Yap CK, Setyawan AD. 2025. Spatio-temporal changes in mangrove density and cover in Sriwulan and Pasar Banggi-Tireman, Central Java, Indonesia. Intl J Bonorowo Wetlands 15: 130-139.* Mangrove ecosystems play a strategic role in supporting ecological integrity, coastal protection, and socio-economic resilience in tropical coastal landscapes by providing essential ecosystem services such as shoreline stabilization, biodiversity support, and livelihood resources for coastal communities. Despite their importance, mangrove systems continue to face sustainability challenges driven by anthropogenic pressures, including land-use conversion, aquaculture expansion, and weak governance arrangements. Existing assessments of mangrove sustainability have predominantly adopted sectoral approaches that emphasize either ecological or socio-economic dimensions in isolation, limiting the ability to diagnose cross-dimensional interactions and structural conditions in which progress in one dimension coexists with persistent constraints in others. As a result, structural sustainability imbalances remain insufficiently examined, particularly in community-managed mangrove systems. This study diagnoses structural sustainability imbalance in a community-managed mangrove ecosystem in Kartika Jaya Village, Central Java, Indonesia, using a cross-sectional, single-site design. A multidimensional assessment was conducted using the Rapid Appraisal for Mangrove Forest (RAP-MForest) method, applying Multidimensional Scaling, leverage analysis, and Monte Carlo simulation. Rather than functioning solely as an evaluative index, RAP-MForest was applied as a diagnostic framework to examine relative performance and sensitivity across ecological, economic, and social dimensions. The results indicate that the ecological (68.16) and social (73.87) dimensions exhibit fairly sustainable conditions, supported by moderate ecosystem resilience and strong community awareness and participation. In contrast, the economic dimension (41.93) shows substantially weaker performance, reflecting limited economic utilization, funding constraints, and weak integration with local development. This cross-dimensional disparity produces a clear structural sustainability imbalance, in which economic underperformance constrains overall system coherence. Conceptually, this study advances sustainability assessment by framing sustainability as a configuration of interacting dimensions rather than an average composite score. Practically, the findings highlight the need for management and policy interventions that prioritize economic leverage points to consolidate existing ecological recovery and social capital within community-based mangrove management.

Keywords: Community-based management, mangrove, multidimensional sustainability, RAP-MForest, structural sustainability imbalance

INTRODUCTION

Mangrove ecosystems represent complex socio-ecological systems that integrate ecological functions with social and economic processes in tropical coastal landscapes. Ecologically, mangroves provide critical services such as shoreline stabilization, wave attenuation, sediment trapping, and the maintenance of coastal water quality, thereby reducing vulnerability to erosion and extreme weather events (Barbier 2019; Friess et al. 2019). Mangrove forests are also globally recognized as highly efficient blue carbon ecosystems, storing substantial amounts of carbon in both biomass and sediments and playing a significant role in climate change mitigation (Hamilton and Friess 2018; Arnaud et al. 2023). In addition, mangroves support high biodiversity by functioning as nursery habitats for fish, crustaceans, and other coastal fauna, contributing to broader marine productivity (Carugati et al. 2018).

Beyond their ecological importance, mangrove ecosystems sustain diverse social and economic functions. Coastal communities depend on mangroves for fisheries, aquaculture, fuelwood, non-timber forest products, and emerging livelihood opportunities such as ecotourism (Walters et al. 2008; Malik et al. 2015). These ecosystem services contribute not only to household income but also to food security and social resilience, particularly in developing tropical countries. Community-based mangrove management has therefore emerged as a widely promoted approach to balance conservation and livelihood needs by fostering local participation, stewardship, and adaptive governance (Kongkeaw et al. 2019; Macamo et al. 2024).

Despite their multifunctionality, tropical mangrove ecosystems remain highly vulnerable. Rapid coastal development, aquaculture expansion, land-use conversion, pollution, and weak institutional coordination continue to drive mangrove degradation across Southeast Asia and other tropical regions (Utami et al. 2024; Apriani and

Delistiani 2025). These pressures disrupt ecological integrity while simultaneously undermining the socio-economic foundations of mangrove-dependent communities, highlighting the need for sustainability assessments that explicitly consider interactions among ecological, economic, and social dimensions rather than treating them in isolation.

Research on mangrove sustainability has expanded considerably over the past two decades; however, much of this literature remains sectoral in nature. Numerous studies emphasize biophysical indicators such as mangrove cover change, species composition, biomass, and carbon stocks (Pham et al. 2019; Sunkur et al. 2024), while social and economic studies tend to focus on participation, perceptions, or valuation of ecosystem services (Afonso et al. 2022; Bakri et al. 2023). This separation constitutes a critical analytical gap, as sustainability is often inferred from improvements within individual dimensions without examining how uneven performance across dimensions may constrain overall system coherence.

An increasing body of evidence indicates that sustainability challenges in mangrove systems are frequently structural rather than uniform. Structural sustainability imbalance refers to a condition in which certain dimensions—typically ecological and social—exhibit relatively strong performance, while others, particularly the economic dimension, remain persistently weak and act as systemic constraints (Kusmana 2011; Sabrina et al. 2022; Ramadhani et al. 2025). Such patterns have been documented in community-managed mangrove systems across Indonesia and Southeast Asia, where successful rehabilitation and high community awareness coexist with limited funding, weak market integration, and low economic returns (Hidayah et al. 2024; Kamakuala et al. 2025). These observations underscore the novelty of framing sustainability not as a composite score, but as a configuration of interacting dimensions characterized by structural imbalance.

The Rapid Appraisal for Mangrove Forest (RAP-MForest) method, adapted from the Rapid Appraisal for Fisheries (RAPFISH) framework, offers a multidimensional diagnostic approach based on Multidimensional Scaling (MDS) that evaluates ecological, economic, and social dimensions separately (Pitcher and Preikshot 2001; Pitcher et al. 2013). When applied diagnostically, RAP-MForest enables the identification of cross-dimensional disparities and leverage attributes that shape sustainability configurations, rather than merely ranking overall performance. However, its explicit use to diagnose structural sustainability imbalance at the community-management scale remains limited in the peer-reviewed literature (Sabrina et al. 2022; Ramadhani et al. 2025).

Based on this perspective, this study hypothesizes that in a community-managed mangrove system, the economic sustainability dimension exhibits lower performance than the ecological and social dimensions, resulting in a structural sustainability imbalance that constrains overall system coherence. Accordingly, this study applies the RAP-MForest approach to a community-managed mangrove ecosystem in a tropical coastal landscape with three objectives: (i) to assess sustainability indices across ecological, economic, and social dimensions; (ii) to identify key leverage attributes contributing to structural sustainability imbalance; and (iii) to derive management- and policy-relevant insights to support integrated community-based mangrove sustainability strategies.

MATERIALS AND METHODS

Study area and community-managed mangrove context

The study was conducted in Kartika Jaya Village, Kendal District, located along the northern coast of Central Java, Indonesia (6°52′6″S, 110°12′22″E). This coastal area represents a typical tropical lowland shoreline characterized by shallow waters, muddy substrates, and tidal dynamics that support mangrove vegetation. The mangrove ecosystem in this village is managed predominantly through community-based initiatives involving local residents, fishers, aquaculture farmers, and village-level organizations. Management activities include small-scale rehabilitation, monitoring, and limited utilization of mangrove resources for livelihoods. Despite ongoing conservation efforts, the system remains exposed to anthropogenic pressures such as land conversion, aquaculture expansion, and infrastructure development, making it a relevant case for sustainability assessment. This study adopts a cross-sectional, single-site design, with Kartika Jaya Village serving as a representative case of a community-managed mangrove system within a broader tropical coastal landscape where ecological functions, economic activities, and social institutions interact closely (Figure 1).

Data collection and respondent selection

Data were collected through a combination of field observation, semi-structured interviews, and questionnaire surveys to capture ecological conditions, management practices, and community perspectives related to mangrove sustainability. Field observations were conducted to document mangrove vegetation condition, signs of degradation, rehabilitation activities, and human use patterns within the study area. These observations provided contextual information to support the interpretation of sustainability attributes.

Interviews and questionnaires were administered to key community members involved in mangrove use and management, including fishers, aquaculture farmers, community leaders, and members of local mangrove conservation groups. The survey instruments were designed to capture respondents' perceptions of ecological conditions, economic benefits, institutional arrangements, and participation in mangrove management.

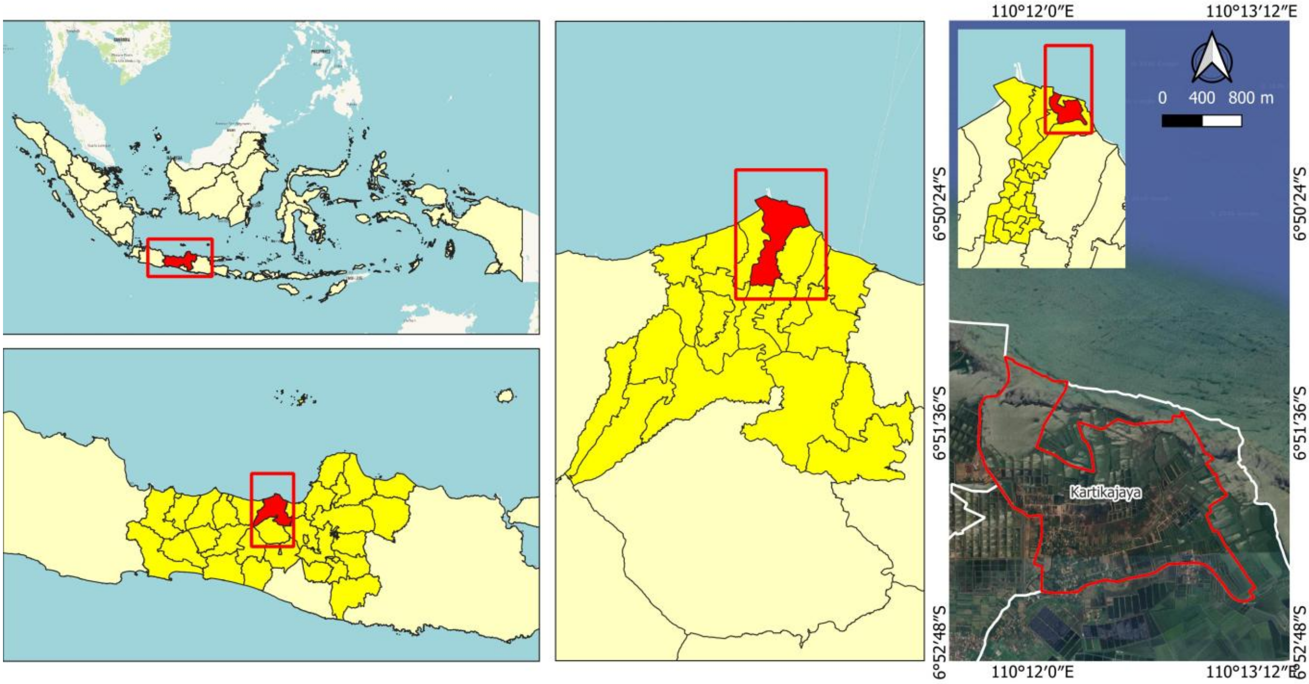

Figure 1. Study area of a community-managed mangrove system in the tropical coastal zone of Central Java, Indonesia

Respondents were selected using purposive sampling to ensure that participants had direct experience and knowledge relevant to mangrove management in the study area. A total of 97 respondents were included, proportionally distributed across the hamlets within Kartika Jaya Village. This sampling approach is appropriate for sustainability assessments that rely on informed stakeholder perspectives rather than statistical generalization. Participation in the study was voluntary, and informed consent was obtained from all respondents prior to interviews and questionnaire administration. To ensure ethical research practice, respondents' identities were kept anonymous, and all information was treated confidentially and used solely for academic purposes. Overall, the respondent profile reflects the primary stakeholder groups whose activities and decisions directly influence the sustainability of the community-managed mangrove system.

Sustainability dimensions and attribute architecture

Sustainability assessment in this study was structured around three interrelated dimensions: ecological, economic, and social, which together represent the core components of community-managed mangrove systems (Table 1). The ecological dimension reflects biophysical integrity, ecosystem functioning, and regenerative capacity of mangrove forests. The economic dimension captures the extent to which mangrove ecosystems contribute to livelihoods, funding availability, and sustainable resource use. The social dimension represents institutional arrangements, community awareness, participation, and governance mechanisms supporting mangrove management.

Attributes within each dimension were selected based on literature review, field observations, and relevance to local management contexts. Rather than functioning as isolated indicators, these attributes collectively represent the internal structure of the mangrove sustainability system. This attribute architecture allows sustainability to be interpreted diagnostically, enabling the identification of cross-dimensional imbalances and leverage points that shape overall system performance.

Each attribute was scored using an ordinal scale following the RAP-MForest framework, in which attribute scores were assigned along a graded continuum from unfavorable to favorable conditions based on field observations and respondent assessments. Specifically, attributes were scored using a standardized ordinal scale ranging from 0 to 4, where lower scores (0-1) represent unfavorable or less sustainable conditions and higher scores (3-4) indicate more favorable or sustainable conditions, following the standard RAP-MForest/RAPFISH procedure. Lower ordinal scores represent poorer or less sustainable conditions, whereas higher ordinal scores indicate better or more sustainable conditions within each dimension.

In the Multidimensional Scaling (MDS) ordination, hypothetical "good" and "bad" reference points were used to anchor the sustainability space, allowing observed attribute scores to be positioned relative to ideal and undesirable conditions. Sustainability indices were subsequently derived by standardizing ordination scores along this continuum, enabling comparative interpretation across ecological, economic, and social dimensions.

Table 1. Structural architecture of ecological, economic, and social attributes used to diagnose sustainability imbalances in community-managed mangrove ecosystems

Dimension	Attrib. code	Attribute description
Ecological	E1	Mangrove species diversity
Ecological	E2	Habitat variation
Ecological	E3	Water quality
Ecological	E4	Mangrove pressure (e.g., land conversion, logging, pollution)
Ecological	E5	Fauna diversity
Ecological	E6	Mangrove rehabilitation activities
Ecological	E7	Seedling availability and natural regeneration
Ecological	E8	Presence of endemic or native mangrove species
Economic	Ec1	Economic utilization of mangrove resources
Economic	Ec2	Availability of management funding
Economic	Ec3	Land-use zoning and spatial allocation
Economic	Ec4	Support for rehabilitation and conservation activities
Economic	Ec5	Contribution of mangroves to household income
Economic	Ec6	Integration of mangrove management with local development
Social	S1	Institutional coordination among stakeholders
Social	S2	Existence and enforcement of local regulations
Social	S3	Community awareness of mangrove functions
Social	S4	Community participation in mangrove management
Social	S5	Attitude toward sustainability and conservation
Social	S6	Role of community leaders and non-governmental organizations

RAP-MForest analysis and sustainability indices

The sustainability status of the community-managed mangrove system was assessed using the Rapid Appraisal for Mangrove Forest (RAP-MForest) method, adapted from the RAPFISH framework and based on Multidimensional Scaling (MDS). This approach transforms multiple sustainability attributes into ordination scores that represent the relative position of the system along a continuum between ideal ("good") and undesirable ("bad") reference conditions. Each attribute was scored on an ordinal scale and subsequently standardized to produce sustainability indices ranging from 0 to 100.

Sustainability indices were classified into three consistent categories applied throughout this study: less sustainable (<50), fairly sustainable (50-75), and sustainable (>75), allowing direct comparison across ecological, economic, and social dimensions. These categories are used solely as interpretative thresholds rather than absolute benchmarks of sustainability. Rather than being interpreted as absolute measures, the resulting indices function as relative diagnostic indicators that reflect comparative performance and internal structural configuration within the system. Differences among dimension-specific indices therefore indicate potential structural sustainability imbalances, where relatively strong dimensions may coexist with weaker ones.

By maintaining separate indices for each dimension, the RAP-MForest approach enables sustainability to be evaluated as a configuration of interacting components rather than as a single aggregated score. This diagnostic interpretation emphasizes relative positioning within the ordination space and provides a principled basis for identifying leverage attributes and priority areas for management intervention, rather than prescribing absolute sustainability status.

Leverage and Monte Carlo analysis

Leverage analysis was conducted to identify attributes that exert the greatest influence on sustainability indices within each dimension. The sensitivity of each attribute was quantified using the Root Mean Square (RMS) of changes in ordination scores resulting from systematic variation of attribute values. Attributes with higher RMS values were interpreted as key leverage factors, as small changes in these attributes produced relatively large shifts in the sustainability index. Importantly, leverage values reflect sensitivity within the ordination space rather than causal relationships, and therefore indicate relative influence rather than direct cause–effect mechanisms. These leverage factors, therefore, represent priority points for management intervention from a diagnostic perspective aimed at reducing structural sustainability imbalances.

To assess the robustness of the RAP-MForest results, a Monte Carlo analysis was applied. This procedure evaluates the potential effects of scoring uncertainty and random variation in respondent assessments on the stability of sustainability indices. Monte Carlo simulations showed minimal deviation between the original and simulated ordination scores, indicating that the derived sustainability indices were robust to scoring uncertainty. Consistency between original and simulated ordination results indicates that the derived indices are not strongly affected by random error. As the analysis is partly based on perception-derived ordinal scoring, the resulting indices should be interpreted as relative diagnostic indicators rather than precise quantitative measurements. Accordingly, the combined use of leverage and Monte Carlo analyses supports comparative assessment and decision-support applications, rather than inferential or predictive claims.

RESULTS AND DISCUSSION

Cross-dimensional sustainability indices

The RAP-MForest analysis revealed clear differences in sustainability performance across ecological, economic, and social dimensions of the community-managed mangrove system (Table 2). The ecological dimension achieved a sustainability index of 68.16, placing it within the fairly sustainable category. This score indicates that, despite ongoing pressures, core ecological functions such as vegetation condition, regeneration potential, and habitat quality remain moderately resilient. The social dimension recorded the highest sustainability index at 73.87, also categorized as fairly sustainable, reflecting relatively strong community awareness, participation, and institutional support for mangrove management.

In contrast, the economic dimension exhibited a substantially lower sustainability index of 41.93, classified as less sustainable. This result highlights limited economic benefits derived from mangrove management, constrained funding mechanisms, and weak integration between conservation activities and local economic development. The disparity between the economic dimension and the other two dimensions indicates that improvements in ecological condition and social engagement have not been accompanied by comparable economic performance.

When examined collectively, these dimension-specific indices reveal an asymmetric sustainability configuration rather than a balanced system. The coexistence of moderately strong ecological and social dimensions (68.16 and 73.87, respectively) with a lagging economic dimension (41.93) provides an initial indication of structural sustainability imbalance within the mangrove management system. Monte Carlo analysis confirmed that these cross-dimensional patterns were stable, as simulated ordination results showed minimal deviation from the original configuration, indicating robustness of the sustainability indices to scoring uncertainty. This imbalance suggests that overall sustainability is constrained not by ecological degradation alone, but by uneven performance across dimensions. All sustainability indices are reported using a consistent two-decimal precision throughout the Results, corresponding tables, and figures to ensure clarity and comparability.

Ecological sustainability structure and leverage attributes

The ecological dimension of the community-managed mangrove system exhibited a fairly sustainable condition, as reflected by its sustainability index and the overall ordination pattern. Field observations and scoring results indicate that mangrove vegetation remains relatively intact in several areas, supported by ongoing rehabilitation activities and the presence of natural regeneration. However, ecological conditions are not uniform across the study area, with localized degradation still evident in zones exposed to higher anthropogenic pressure.

Leverage analysis identified mangrove pressure as the most influential ecological attribute shaping sustainability outcomes, indicating that the intensity of human-induced disturbances primarily controls ecological performance. Water quality and seedling availability formed a second tier of sensitive attributes, reflecting their critical roles in maintaining regeneration processes and habitat suitability. Together, these attributes define a hierarchical sensitivity structure within the ecological dimension, where pressure acts as the dominant driver and regenerative capacity functions as a stabilizing mechanism.

Overall, ecological sustainability appears to be governed by the balance between ongoing pressures and the system's regenerative potential. While current conditions support moderate ecological resilience, persistent increases in pressure or declines in water quality and seedling availability would likely disrupt this balance and reduce ecosystem stability (Figure 2). When interpreted in conjunction with the cross-dimensional results, the ecological sustainability index of 68.16 contrasts with a substantially lower economic index of 41.93 and a higher social index of 73.87, indicating that ecological performance alone does not determine overall sustainability but forms part of a structurally imbalanced configuration that is synthesized in the subsequent section.

Economic constraints underlying sustainability imbalance

The economic dimension showed the weakest sustainability performance among the assessed dimensions, indicating a fundamental constraint within the mangrove management system. Limited economic returns from mangrove-related activities, combined with inadequate funding and weak integration with local development initiatives, restrict the capacity of the system to support sustainable livelihoods. These conditions suggest that economic processes have not evolved in parallel with ecological recovery and social engagement.

Table 2. Cross-dimensional sustainability indices revealing structural imbalances among ecological, economic, and social dimensions

Dimension	Sustainability index (%)	Sustainability category
Ecological	68.16	Fairly sustainable
Economic	41.93	Less sustainable
Social	73.87	Fairly sustainable

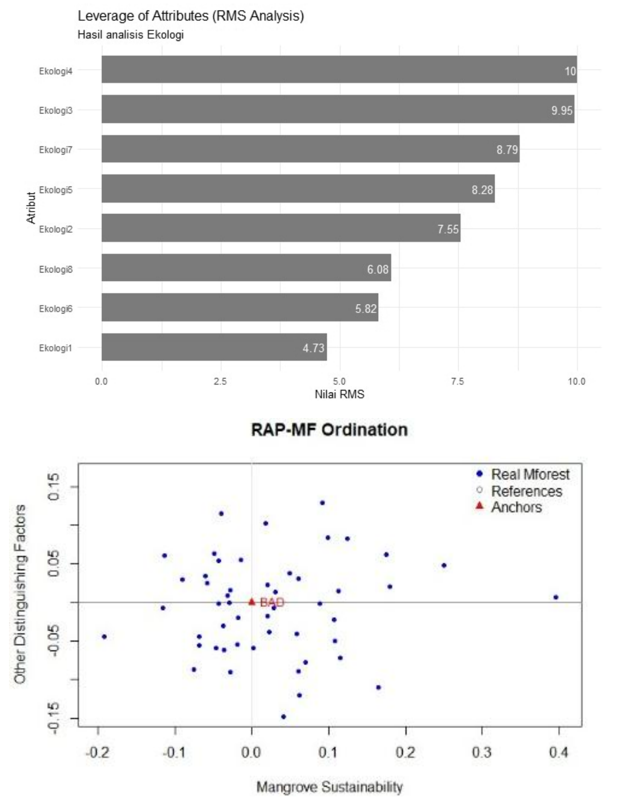

Figure 2. Ecological sustainability structure and leverage attributes shaping mangrove system resilience, derived from RAP-MForest Multidimensional Scaling (MDS) ordination and RMS-based leverage analysis

Leverage analysis revealed that economic utilization of mangrove resources constitutes the primary controlling attribute within the economic dimension. Management funding and support for rehabilitation formed additional high-sensitivity attributes, indicating that financial mechanisms strongly influence economic sustainability. This configuration reflects a structurally constrained economic subsystem, where limited incentives and resource flows restrict the translation of conservation efforts into tangible economic benefits.

As a result, the economic dimension functions as a systemic bottleneck. Despite favorable ecological conditions and strong social capital, economic limitations constrain overall sustainability by weakening feedbacks between conservation outcomes and livelihood improvement. This bottleneck position underscores the structural nature of the sustainability imbalance observed in the system, as illustrated by the RAP-MForest Multidimensional Scaling (MDS) ordination and leverage-based sensitivity output for the economic dimension (Figure 3).

Social drivers reinforcing sustainability

The social dimension exhibited a relatively high sustainability performance, indicating that social processes play a supportive role in maintaining mangrove management outcomes. High levels of community awareness regarding mangrove functions, coupled with active participation in conservation and rehabilitation activities, contribute positively to the overall sustainability profile. These social strengths reflect the presence of shared values, collective action, and local commitment to mangrove protection.

Leverage analysis identified community awareness and attitudes toward sustainability as the most sensitive social attributes influencing the sustainability index. Community participation and the role of local leaders and organizations also emerged as influential factors, indicating that institutional and informal governance structures help reinforce sustainable behavior. Changes in these attributes resulted in noticeable shifts in social ordination scores, underscoring their importance in shaping social resilience.

Despite these strengths, the social dimension operates within the constraints imposed by limited economic performance. Strong awareness and participation have not yet translated into adequate economic incentives or livelihood diversification. This contrast highlights a condition in which social capital supports conservation efforts but is insufficient to overcome economic limitations on its own, thereby reinforcing the cross-dimensional sustainability imbalance observed in the system (Figure 4).

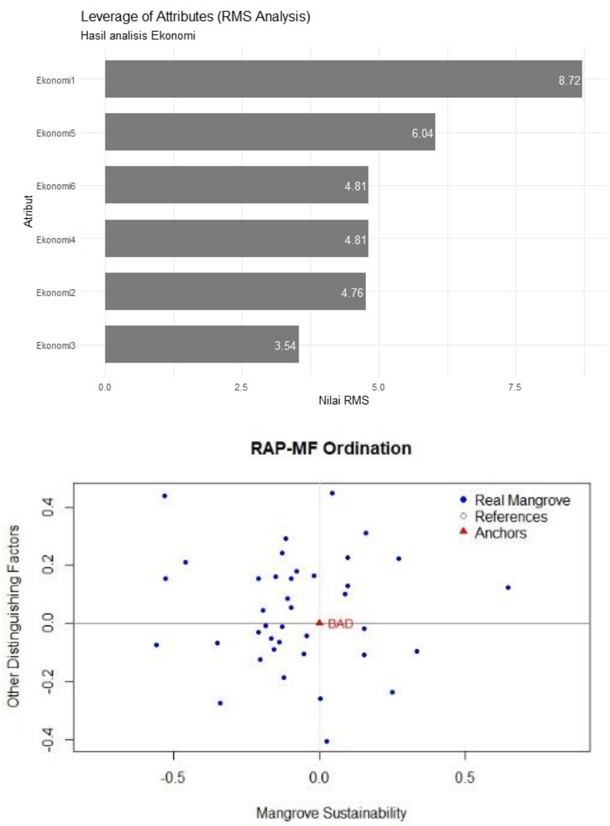

Figure 3. Economically driven constraints underlying the sustainability imbalance in mangrove management, derived from RAP-MForest Multidimensional Scaling (MDS) ordination and RMS-based leverage analysis of economic attributes

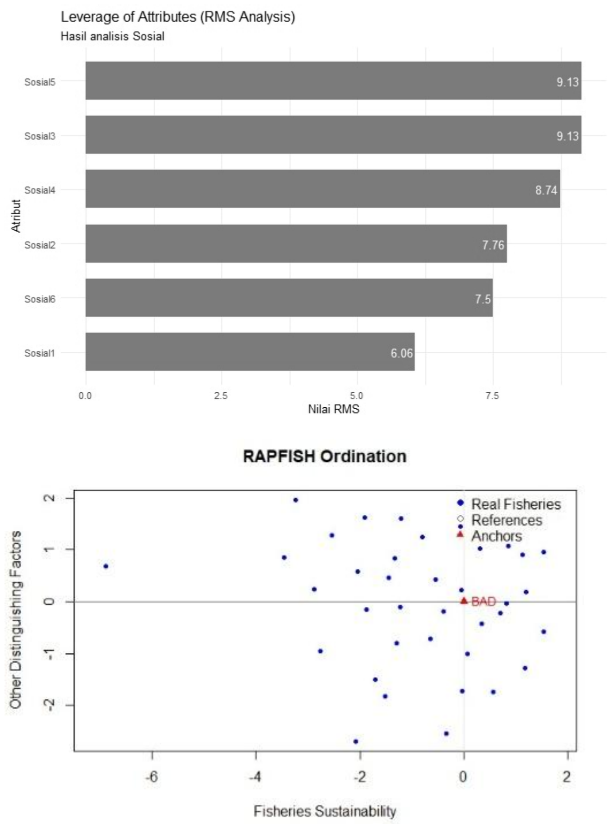

Figure 4. Social drivers reinforcing sustainability despite economic limitations in community-managed mangroves, derived from RAP-MForest Multidimensional Scaling (MDS) ordination and RMS-based leverage analysis of social attributes

Synthesis of structural sustainability imbalance

Integration of the ecological, economic, and social results reveals a clear pattern of structural sustainability imbalance within the community-managed mangrove system. The ecological dimension achieved a sustainability index of 68.16, and the social dimension reached 73.87, indicating fairly sustainable conditions supported by moderate ecosystem resilience, strong community awareness, and active participation. In contrast, the economic dimension recorded a substantially lower sustainability index of 41.93, consistently exhibiting weaker performance and limiting the system's ability to translate ecological recovery and social capital into sustainable livelihood outcomes.

This cross-dimensional configuration is effectively summarized through a kite diagram, which visualizes the asymmetric distribution of sustainability indices across dimensions. The pronounced contraction of the economic axis—corresponding to an index value of 41.93—relative to the more extended ecological (68.16) and social (73.87) axes illustrates how economic constraints structurally narrow the overall sustainability profile of the system (Figure 5). Rather than reflecting uniform underperformance across all dimensions, the diagram highlights imbalance as a defining structural characteristic, in which relatively strong ecological and social dimensions coexist with a persistently lagging economic dimension.

Within this configuration, the economic dimension emerges as the primary leverage and intervention point for rebalancing sustainability performance. While ecological integrity and social capacity provide a supportive foundation, strengthening economic mechanisms—such as improving sustainable resource utilization, funding availability, and linkage with local development—becomes essential to reduce structural imbalance and enhance overall system coherence.

Figure 5. Kite diagram summarizing structural sustainability imbalance among ecological, economic, and social dimensions based on RAP-MForest results

Discussion

Diagnosing structural sustainability imbalance in mangrove systems

The results of this study demonstrate that sustainability in community-managed mangrove systems is best understood as a structural sustainability imbalance rather than a uniform condition. The coexistence of moderately strong ecological and social dimensions with a comparatively weak economic dimension indicates that sustainability challenges are not driven by ecological degradation alone. Instead, they emerge from uneven interactions among system components, where persistent economic constraints and weak economic linkages constrain progress in certain dimensions. Similar patterns have been reported in mangrove systems across Southeast Asia, Africa, and Latin America, where rehabilitation success and high community engagement coexist with limited livelihood diversification and financial returns (Friess et al. 2019; Sunkur et al. 2023).

The concept of structural sustainability imbalance provides a useful lens to interpret these outcomes. Rather than treating sustainability as an average score derived from multiple indicators, this perspective emphasizes the relative configuration of dimensions and their internal coherence. In mangrove systems, ecological recovery may enhance habitat quality and carbon storage, while strong social capital promotes participation and compliance; however, in the presence of economic underperformance and financial limitations, these gains remain fragile. Studies from Vietnam, Bangladesh, and the Philippines similarly report that economic underperformance—manifested through limited market access, weak incentives, or insufficient funding— often undermines long-term sustainability despite ecological improvements (Portorreal et al. 2024; Ebeler et al. 2025).

Viewing sustainability as a configuration also aligns with broader socio-ecological systems theory, which highlights the importance of cross-scale interactions and feedback among ecological processes, governance structures, and economic drivers (Ostrom 2009; Berkes 2017). From this standpoint, imbalance is not an anomaly but a common system state arising from differential rates of adaptation across dimensions. The RAP-MForest results illustrate that ecological and social dimensions in the study area have adapted more rapidly—through rehabilitation and collective action—than the economic dimension, which remains constrained by structural financial and institutional limitations beyond local control.

This diagnostic interpretation has important implications. It suggests that improving sustainability does not necessarily require further ecological interventions or awareness campaigns, but rather targeted efforts to address economic constraints and weak economic linkages that inhibit system coherence. International experiences indicate that integrating mangrove conservation with sustainable value chains, payment for ecosystem services, or community-based enterprises can reduce such imbalances when supported by enabling governance and financing mechanisms (Locatelli et al. 2014; Zhang et al. 2024). Consequently, sustainability should be assessed and managed as a relational configuration, where balance among dimensions is as critical as performance within individual components.

Comparison with other tropical mangrove systems

The structural sustainability imbalance identified in this study is consistent with patterns reported from other tropical mangrove systems, particularly in Southeast Asia and deltaic coastal regions. Across Indonesia, Vietnam, Thailand, and the Philippines, numerous studies document situations in which mangrove rehabilitation and community participation have improved ecological conditions, while economic benefits for local communities remain limited or unevenly distributed (Friess and Webb 2014; Malik et al. 2015; Ebeler et al. 2025). These findings suggest that the imbalance observed in Kartika Jaya Village reflects a broader regional tendency rather than an isolated local condition.

In major delta systems such as the Mekong, Ganges–Brahmaputra, and Irrawaddy deltas, similar dynamics have been reported. Ecological restoration and regulatory enforcement have often succeeded in stabilizing mangrove cover, yet economic sustainability remains constrained by insecure tenure, restricted market access, and dependence on low-value resource use (Datta et al. 2012; Sunkur et al. 2023). Community-based management has strengthened social cohesion and awareness, but without complementary economic instruments, these systems continue to exhibit structural imbalance between conservation outcomes and livelihood resilience. From a diagnostic perspective, such cross-dimensional imbalances indicate the potential relevance of policy instruments that specifically target economic leverage points, including payment for ecosystem services schemes, development of sustainable mangrove-based value chains, rehabilitation financing mechanisms, or community-based enterprise models, without presupposing their current application in the studied systems.

Comparative evidence from tropical coastal communities in Africa and Latin America further reinforces this pattern. Studies from Mozambique, Kenya, and Ecuador indicate that strong local institutions and collective action can sustain mangrove protection, but economic incentives frequently lag, limiting long-term system coherence (Walters et al. 2008; Romañach et al. 2018). These cross-regional similarities underscore that economic underperformance is a recurrent bottleneck in community-managed mangrove systems globally.

Within this international context, the present study contributes by explicitly framing these disparities as a structural sustainability imbalance rather than as independent shortcomings of individual dimensions. By applying RAP-MForest as a diagnostic tool, this research advances the global discourse on mangrove sustainability from descriptive assessments toward configuration-based interpretations. This approach aligns with emerging calls in the literature to move beyond single-dimension success metrics and to evaluate how ecological, social, and economic components interact to shape long-term sustainability trajectories in tropical coastal systems (Ostrom 2009; Berkes 2017).

Governance and economic bottlenecks in community-based management

The findings of this study indicate that governance-related economic constraints constitute the principal structural limitation in community-based mangrove management within the specific context of the studied site. Although local institutions and community participation provide a strong social foundation, limited and unstable funding remains a persistent challenge. Community-based mangrove initiatives often rely on short-term project support, voluntary labor, or external assistance, which restricts the continuity and scalability of management activities. Similar funding constraints have been widely reported across Southeast Asian mangrove systems, where the absence of sustained financial mechanisms undermines long-term economic viability (Locatelli et al. 2014; Malik et al. 2015).

In addition to funding limitations, weak market integration represents a critical economic barrier. Mangrove-related products and services, such as sustainable fisheries, ecotourism, or non-timber forest products, frequently lack access to stable value chains and fair pricing mechanisms. As a result, conservation-compatible livelihoods remain marginal and insufficient to offset opportunity costs associated with land conversion or intensive aquaculture. Comparative studies from Vietnam, Bangladesh, and Indonesia consistently show that without market access and economic incentives, community engagement alone cannot sustain mangrove conservation efforts (Zhang et al. 2024; Ebeler et al. 2025).

Institutional coordination further shapes these economic outcomes. While community organizations often function effectively at the local level, coordination with higher-level government agencies, private sector actors, and financial institutions is frequently fragmented. This institutional disconnect limits access to technical support, legal recognition, and investment opportunities, reinforcing economic underperformance despite strong social capital (Friess et al. 2019; Portorreal et al. 2024). These governance gaps should be interpreted as diagnostic features of the studied community-managed mangrove system rather than as statistically generalizable conditions across all mangrove contexts.

Taken together, these conditions reflect a structural sustainability imbalance, rather than a lack of community commitment or ecological potential. Based on the diagnostic results of this single-site, cross-sectional assessment, improving mangrove sustainability requires governance arrangements that prioritize rebalancing economic performance relative to ecological and social dimensions, rather than expanding the indicator set. From a policy perspective, this implies targeted support for stable financing mechanisms and market-oriented instruments that can strengthen economic linkages without undermining existing community-based governance structures. Without addressing these structural economic constraints, community-based mangrove systems are likely to remain in a state of partial sustainability, where ecological and social gains cannot be fully consolidated into durable socio-economic outcomes.

Implications for sustainability diagnostics and management priorities

The findings of this study highlight the value of RAP-MForest not merely as an evaluative index but as a diagnostic tool for informing sustainability-oriented policy and management decisions. By disaggregating sustainability into ecological, economic, and social dimensions, RAP-MForest enables policymakers to identify structural imbalances that are often obscured by aggregated indicators. This diagnostic capacity is particularly relevant for mangrove systems, where apparent ecological success may mask underlying economic fragility. Similar calls for diagnostic rather than descriptive sustainability assessments have been emphasized in international socio-ecological literature (Ostrom 2009; Berkes 2017).

The leverage analysis provides a practical basis for prioritizing management interventions. Rather than allocating resources evenly across all dimensions, the results suggest that targeted interventions addressing high-sensitivity attributes can yield disproportionate improvements in overall sustainability. In the present case, economic attributes related to funding availability, resource utilization, and support mechanisms emerged as critical leverage points. International experiences demonstrate that addressing such leverage attributes through incentive-based instruments, such as payment for ecosystem services, sustainable value chains, or community-based enterprises, can significantly reduce structural imbalances in mangrove systems (Locatelli et al. 2014; Zhang et al. 2024).

From a broader policy perspective, the diagnostic insights generated by RAP-MForest are highly relevant for tropical coastal governance. Many coastal management policies continue to prioritize ecological indicators, such as mangrove cover or biomass, as proxies for sustainability. However, the results of this study reinforce the argument that long-term sustainability depends on balancing ecological recovery with economic viability and social capacity. Integrating diagnostic tools like RAP-MForest into coastal planning frameworks can help align conservation objectives with livelihood development, thereby enhancing policy coherence across sectors (Friess et al. 2019; Sunkur et al. 2023).

Ultimately, adopting a diagnostic approach shifts management priorities from short-term ecological targets toward structural coherence among dimensions. This shift is essential for designing adaptive, inclusive, and resilient mangrove management strategies in tropical coastal landscapes facing increasing environmental and socio-economic pressures.

Methodological considerations and limitations

Several methodological considerations should be acknowledged when interpreting the results of this study. First, the RAP-MForest assessment relies partly on perception-based scoring derived from interviews and questionnaires. Although respondents were purposively selected for their direct involvement and knowledge of mangrove management, subjective judgments may introduce bias. To mitigate this limitation, leverage and Monte Carlo analyses were applied to evaluate the sensitivity and robustness of sustainability indices, providing greater confidence in the observed patterns.

Second, the study adopts a cross-sectional design focused on a single community-managed mangrove system. As such, the results are not intended for statistical generalization across all tropical mangrove landscapes. Instead, the findings should be interpreted as a context-specific diagnosis that illustrates a broader structural pattern reported in comparable systems. Longitudinal data and multi-site comparisons would be valuable for capturing temporal dynamics and testing the persistence of structural imbalances over time.

Despite these limitations, the diagnostic strength of the approach represents a key contribution. By disaggregating sustainability into multiple dimensions and identifying leverage attributes, RAP-MForest enables a nuanced interpretation of system configuration rather than a simplistic performance ranking. This capacity makes the method particularly useful for decision-support and adaptive management in complex socio-ecological systems, where understanding structural relationships is as important as measuring outcomes.

In conclusion, this study demonstrates that sustainability in community-managed mangrove ecosystems is best interpreted as a structurally imbalanced configuration rather than a uniform condition. The RAP-MForest analysis shows that the ecological dimension reached a sustainability index of 68.16 and the social dimension 73.87, both indicating fairly sustainable performance, whereas the economic dimension recorded a substantially lower index of 41.93. This numerical disparity confirms that overall sustainability is constrained by cross-dimensional imbalance, in which relatively strong ecological and social conditions coexist with persistent economic underperformance. From a practical perspective, the results indicate that the economic dimension represents the primary leverage point for improving system coherence. Diagnostic leverage analysis suggests that targeted interventions focusing on funding availability, economic utilization of mangrove resources, and institutional support are more likely to strengthen overall sustainability than additional ecological rehabilitation or awareness-based initiatives alone. Strengthening economic mechanisms is therefore essential to consolidate existing ecological recovery and social capital within community-based mangrove management. Several limitations should be acknowledged. This assessment is based on a cross-sectional design, a single study site, and perception-based ordinal scoring, which restrict statistical generalization. Accordingly, the findings should be interpreted as diagnostic and context-specific. Future research should adopt longitudinal and multi-site comparative approaches to examine how structural sustainability imbalances evolve over time and across different mangrove management contexts, while maintaining a focus on rebalancing performance among sustainability dimensions rather than expanding indicator sets.

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