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Key Drivers of Mangrove Rehabilitation Success in Ujungalang Village, Indonesia: A MICMAC-Based Stakeholder Analysis

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Abstract: Mangrove ecosystems face severe threats in Indonesia due to anthropogenic pressures and weak governance. This study analyzes factors influencing mangrove rehabilitation success in Ujungalang Village, Cilacap Regency, using MICMAC (Matrix of Cross Impact Multiplications Applied to Classification) method. Through interviews with six key stakeholders, ten variables were identified across biophysical, socio-economic, and institutional dimensions. MICMAC analysis revealed government policy, local institutional support, and external institutional engagement as driving variables, while community participation functioned as a crucial relay variable. The findings emphasize policy coherence, institutional capacity building, and sustained community engagement in creating improvement cycles. This research provides the first comprehensive MICMAC-based framework for understanding rehabilitation dynamics in Indonesian coastal contexts, with practical implications for policy integration and strengthening local governance structures.

Keywords: Indonesia; Mangrove rehabilitation; MICMAC; Stakeholder analysis; Ujungalang Village.

Introduction

Mangrove forests are dynamic and highly productive coastal ecosystems that provide a wide range of ecological, economic, and social services (Hagger *et al*. 2020). Their functions include acting as natural barriers against storm surges and coastal erosion, regulating carbon fluxes through carbon sequestration, maintaining water quality, and serving as nurseries for various aquatic species (Friess *et al*. 2024). These functions are critical for the sustainability of coastal livelihoods, particularly in countries like Indonesia that are heavily reliant on coastal and marine resources.

Indonesia holds the largest area of mangrove forests globally, encompassing over 3 million hectares, which accounts for approximately 23% of the world's total mangrove coverage (Winarso et al. 2023). However, these ecosystems face escalating threats from urban expansion, aquaculture, agricultural encroachment, and infrastructure development (Palit et al. 2022). According to Mohanty et al. (2024), even though the rate of mangrove deforestation has decelerated, the degradation of ecosystem services remains a major concern, particularly in critical habitats like Segara Anakan Lagoon in Central Java.

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The Segara Anakan region, including Ujungalang Village, has experienced significant mangrove degradation due to sedimentation, pollution, and uncoordinated land use change (Jennerjahn et al. 2022). Studies by Nordhaus et al. (2019) revealed a marked decline in mangrove species diversity, from 26 species in 2009 to just 17 species in 2015, along with a substantial decrease in biomass from 209 tons/ha to 141 tons/ha during the same period. This degradation has profound implications for coastal resilience, biodiversity conservation, and community livelihoods in the region.

Various rehabilitation initiatives have been implemented in Ujungalang Village as a response to the degradation. Notable efforts include the planting of 100,000 mangrove seedlings by Jasa Tirta I (2024) and Pertamina's commitment to plant 1 million mangrove trees in the Segara Anakan area (Pertamina 2016). Additionally, the Center for Coastal and Marine Resources Studies (PKSPL IPB University) has collaborated with the Indonesia Deposit Insurance Corporation (LPS) on mangrove rehabilitation programs in Kampung Laut, demonstrating a multi-stakeholder approach to ecosystem restoration (PKSPL IPB 2024).

Despite these commendable efforts, the effectiveness of mangrove rehabilitation programs often faces challenges related to planning, implementation, monitoring, and sustainability (Ellison et al. 2020). Fatimah et al. (2022) highlighted coordination issues among stakeholders and resource limitations as significant constraints to successful mangrove conservation. The complex interplay between ecological, socio-economic, and institutional factors necessitates a systems approach to understanding the dynamics of mangrove rehabilitation (Ellison et al. 2020).

This study represents the first application of the Matrix of Cross Impact Multiplications Applied to Classification (MICMAC) method to analyze mangrove rehabilitation dynamics in Indonesian coastal contexts. While previous research has examined individual factors affecting mangrove conservation, this research provides a novel systems-based approach that maps the complex interdependencies between biophysical, socio-economic, and institutional variables. The novelty lies in its comprehensive stakeholder-driven analysis that identifies strategic leverage points through influence-dependence relationships, moving beyond traditional single-factor analyses to understand system-wide dynamics.

The research is critically important for several reasons. First, it addresses the persistent gap between rehabilitation investments and outcomes by identifying why many well-funded initiatives fail to achieve sustainable results. Second, given Indonesia's position as the world's largest mangrove holder facing continued degradation pressures, understanding effective rehabilitation strategies has global conservation implications. Third, the systems approach provides actionable insights for policymakers and practitioners by identifying which interventions will have the greatest impact on overall system performance. Finally, the research contributes to evidence-based coastal management by providing a replicable analytical framework that can guide rehabilitation efforts in similar socio-ecological contexts across tropical coastal regions.

This study adopts the MICMAC method to systematically analyze the influence and dependence relationships among various factors affecting mangrove rehabilitation in Ujungalang Village. MICMAC is a structural analysis tool that helps identify the most influential variables in a complex system (Manzano-Solís et al. 2019). By mapping these relationships, the research aims to identify strategic leverage points that can enhance the effectiveness of rehabilitation efforts.

The study contributes to the growing body of literature on mangrove rehabilitation by offering a comprehensive framework that integrates biophysical, socio-economic, and institutional dimensions. The findings provide valuable insights for policymakers, conservation practitioners, and local communities engaged in mangrove rehabilitation initiatives. By identifying the key drivers of success, this research supports the development of more effective strategies for mangrove ecosystem restoration and management in Indonesia and beyond.

Method

Study area

Ujungalang Village is situated in Kampung Laut Ujungalang Village is located in Kampung Laut Sub-district, Cilacap Regency, Central Java, Indonesia. Positioned within the Segara Anakan Lagoon, this coastal village covers 5,688 hectares dominated by mangrove ecosystems (3,947 hectares or 70% of total area). The area is characterized by delta geomorphology formed by sedimentation from Citanduy, Cibeureum, and Cikawung Rivers, with access primarily via waterways due to its remote location (Utami et al. 2016).

The village represents one of the largest mangrove ecosystem pockets in Cilacap Regency, encompassing primary, secondary, and rehabilitation areas managed by government and local communities over the past two decades (Ratini et al. 2016; Winarso et al. 2023). Active community participation through institutions like Patra Krida Wana Lestari Farmer Group in rehabilitation programs, combined with ongoing environmental changes from sedimentation and hydrological dynamics, makes this location ideal for analyzing

mangrove rehabilitation success factors in remote coastal areas.

Data Collection

This study employed a qualitative research approach, with primary data collected through in-depth interviews with six key stakeholders involved in mangrove rehabilitation in Ujungalang Village. The stakeholders were selected using purposive sampling to ensure representation from different sectors and perspectives, following recommendations for effective stakeholder engagement in mangrove management (Ellison *et al*. 2020). The selection of diverse stakeholders was critical as successful mangrove rehabilitation requires collaboration across multiple governance levels and sectors (Damastuti *et al*. 2022).

The respondents represented different institutional levels and perspectives in the mangrove rehabilitation system. A representative of local government was included through the Village Secretary of Ujungalang, providing insights into local governance dynamics and policy implementation challenges. Community perspectives were captured through one community leader serving as Head of a neighborhood unit (RT) and one leader of a local mangrove farmer group, ensuring representation of both general community interests and specialized livelihood concerns. Government agency perspectives were obtained from two representatives from the Department of Environment and Department of Marine Affairs and Fisheries, as these are the authorized government entities responsible for mangrove management policy and implementation. Finally, private sector engagement was represented through one representative from Pertamina RU IV's Corporate Social Responsibility (CSR) program, which has been actively involved in mangrove rehabilitation initiatives in the area.

The interviews were conducted using semi-structured questionnaires focused on identifying factors influencing mangrove rehabilitation, their interrelationships, and the roles of different stakeholders (Fauzi 2019). The questionnaire was structured according to the MICMAC analysis requirements, wherein each of the ten pre-identified variables was assessed against all other variables. This resulted in a comprehensive evaluation matrix comprising 90 cross-influence questions (10 variables × 9 other variables), as determined during the research proposal presentation with advisors and seminar participants. Each stakeholder was required to evaluate the influence of each variable on every other variable using the standardized MICMAC scoring scale (Fauzi 2019).

Each interview lasted approximately 60-90 minutes and covered aspects related to biophysical conditions (15 questions), socio-economic factors (27 questions), and institutional arrangements and policy frameworks (48 questions) relevant to mangrove rehabilitation. The distribution of questions corresponded to the number of variables within each dimension and their cross-relationships as required by the MICMAC methodology.

All interviews were recorded with permission and later transcribed for analysis. The participants' identities were not anonymized in the research as agreed upon during the consent process, and this approach aligns with the standard practices for stakeholder analysis in the region. Ethical clearance was obtained from the relevant institutional review board prior to data collection, with full disclosure to participants regarding the use of their professional identities and institutional affiliations in the published research. All participants provided written informed consent for both the recording of interviews and the non-anonymized use of their responses in subsequent analysis and publication.

Data analysis

The MICMAC (Matrix of Cross Impact Multiplications Applied to Classification) method was used to analyze the data (Fauzi 2019). This structural analysis technique helps identify the key variables in a system based on their influence and dependence relationships. The analysis process began with variable identification based on the interview data, literature review, and discussions with academic advisors as subject matter experts. Ten variables affecting mangrove rehabilitation in Ujungalang Village were identified and categorized into three dimensions (Damastuti et al. 2022; Ellison et al. 2020). The biophysical dimension included mangrove density (Ker_Mang), species diversity (Jen_Mang), and water salinity (Sal_Air). The socio-economic dimension encompassed household income (Pend_RT), community participation in rehabilitation (Part_RehMa), and perception of mangrove benefits (Persepsi). The institutional dimension comprised local institutional support (Lemb_Lokal), government policy (Keb_Pem), external institutional support (Lem_NonLok), and corporate social responsibility support (CSR).

The construction of the Direct Influence Matrix (MDI) involved assessing the influence of each variable on every other variable using a scale of 0-3, where 0 represents no influence, 1 represents weak influence, 2 represents moderate influence, and 3 represents strong influence, following the standardized MICMAC evaluation methodology (Fauzi 2019). The assessments were based on the stakeholders' perspectives as expressed during the interviews. The cumulative scores from all six stakeholders were compiled to generate the final MDI values for each variable pair.

Data processing utilized LIPSOR MICMAC software to analyze the direct and indirect relationships among variables (Fauzi 2019). The software generates

influence-dependence maps and network diagrams that visually represent the system dynamics. Based on their influence and dependence scores, variables were classified into four quadrants. Quadrant I represents Input/Driving Variables with high influence and low dependence. Quadrant II contains Link/Relay Variables showing high influence and high dependence. Quadrant III includes Output/Dependent Variables characterized by low influence and high dependence. Quadrant IV encompasses Autonomous/Excluded Variables with both low influence and low dependence.

The MICMAC method also calculates the Matrix of Indirect Influences (MII), which reveals longer-term relationships and feedback loops in the system. This analysis provides insights into the system's behavior over time and identifies variables that may have significant indirect effects. The results of this analysis were then interpreted to identify key leverage points for enhancing mangrove rehabilitation success in Ujungalang Village.

Result and Discussion

Result

Matrix of Direct Influence (MDI)

The analysis of direct influences among the ten identified variables revealed significant patterns in their relationships. Figure 1 presents the Matrix of Direct Influence (MDI), showing the intensity of direct impacts between variables in the mangrove rehabilitation system of Ujungalang Village.

	1 : Ker_Mang	2 : Jen_Mang	3 : Sal_Air	4 : Pend_RT	5 : Part_RehMa	6 : Persepsi	7 : Lemb_Lokal	8 : Keb_Pem	9 : Lem_NonLok	10 : CSR
1 : Ker_Mang	0	3	1	1	1	2	0	0	0	0
2 : Jen_Mang	3	0	1	1	1	2	0	0	0	0
3 : Sal_Air	3	3	0	0	0	1	0	0	0	0
4 : Pend_RT	1	1	0	0	2	3	1	0	0	0
5 : Part_RehMa	3	2	0	2	0	3	2	1	1	1
6 : Persepsi	2	2	0	2	3	0	2	1	1	1
7 : Lemb_Lokal	3	2	1	2	3	3	0	1	1	1
8 : Keb_Pem	3	3	1	2	3	2	3	0	2	3
9 : Lem_NonLok	3	3	1	2	3	2	2	1	0	2
10 : CSR	3	2	1	2	3	2	2	1	1	0

Figure 1. Matrix of Direct Influence (MDI) among ten variables affecting mangrove rehabilitation in Ujungalang Village.

The MDI analysis reveals that Government Policy (Keb_Pem) has the highest total influence score (16), indicating its dominant role in shaping other variables within the system. It exerts particularly strong influence (score of 3) on Local Institutional Support (Lemb_Lokal) and Community Participation in Rehabilitation (Part_RehMa), demonstrating the critical role of policy frameworks in enabling local action and community engagement.

Local Institutional Support (Lemb_Lokal) emerges as the second most influential variable (score of 12), with strong effects on Community Participation (3) and moderate impacts on Perception of Mangrove Benefits (2) and Mangrove Density (2). This highlights the important mediating role that local institutions play in translating policies into community action and ecological outcomes.

Community Participation in Rehabilitation (Part_RehMa) ranks third in influence (10), with a strong direct impact on Mangrove Density (3). This confirms the direct link between community involvement and physical rehabilitation success.

In terms of dependence, Mangrove Density (Ker_Mang) shows the highest dependence score (13), followed by Community Participation (12), indicating that these variables are significantly affected by other factors in the system. This positions Mangrove Density as a key outcome variable that reflects the effectiveness of the entire rehabilitation system.

Classification of Variables by Influence-Dependece

Based on their influence and dependence scores, the variables were mapped onto an influence-dependence diagram to classify them into four categories (Figure 2).

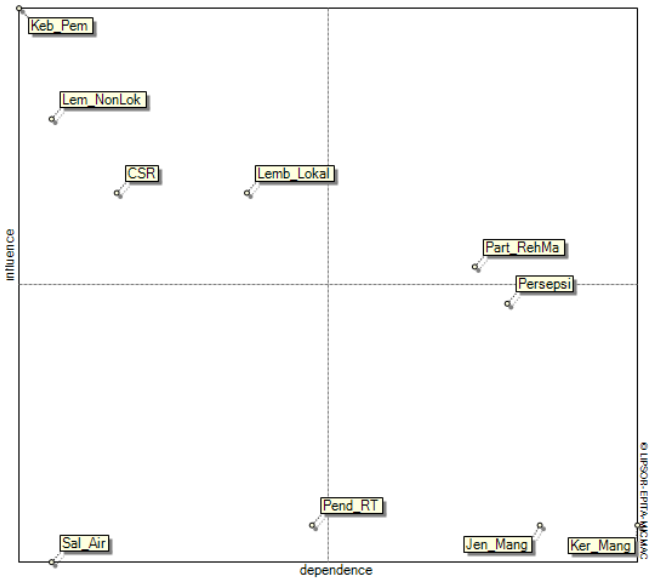

Figure 2. Influence-Dependence Map showing the classification of variables affecting mangrove rehabilitation in Ujungalang Village.

The analysis classified the variables into four distinct quadrants, each representing different roles

within the rehabilitation system. Quadrant I contains the driving variables characterized by high influence and low dependence, including Government Policy (Keb_Pem), Local Institutional Support (Lemb_Lokal), External Institutional Support (Lemb_NonLok), and CSR Support (CSR). These variables function as primary drivers of the system with significant influence on other variables but are relatively independent. Government Policy emerged as the most powerful driver with the highest influence score. Local Institutional Support, External Institutional Support, and CSR Support also demonstrated high influence with relatively low dependence, positioning them as key driving forces in the mangrove rehabilitation system.

Quadrant II represents relay variables exhibiting both high influence and high dependence, with Community Participation in Rehabilitation (Part_RehMa) being the sole variable in this category. This variable functions as a strategic connector within the system, amplifying the effects of driving variables and transmitting them to outcome variables. Its position indicates that community participation both shapes and is shaped by other system elements, making it a critical intermediary factor.

Quadrant III encompasses output variables characterized by low influence and high dependence, including Mangrove Density (Ker_Mang), Species Diversity (Jen_Mang), and Perception of Mangrove Benefits (Persepsi). These output variables are highly dependent on other system factors but have limited influence themselves. This confirms their role as key indicators and outcomes of rehabilitation success, being shaped by the more influential variables in the system rather than driving system behavior.

Quadrant IV contains autonomous variables with both low influence and low dependence, including Water Salinity (Sal_Air) and Household Income (Pend_RT). These variables exhibit relatively low influence and dependence within the system. While they may play supporting roles, they are not primary determinants of system behavior in the context of mangrove rehabilitation in Ujungalang Village.

Network of Direct Influences

The analysis of direct influences was further visualized through a network diagram that illustrates the relationships between variables (Figure 3).

The network diagram reveals several key relationships within the rehabilitation system. Government Policy (Keb_Pem) has strong direct influences on Local Institutional Support (Lemb_Lokal) and Community Participation (Part_RehMa), confirming its role as a primary system driver. This demonstrates how policy frameworks create enabling conditions that activate local institutional responses and community engagement processes.

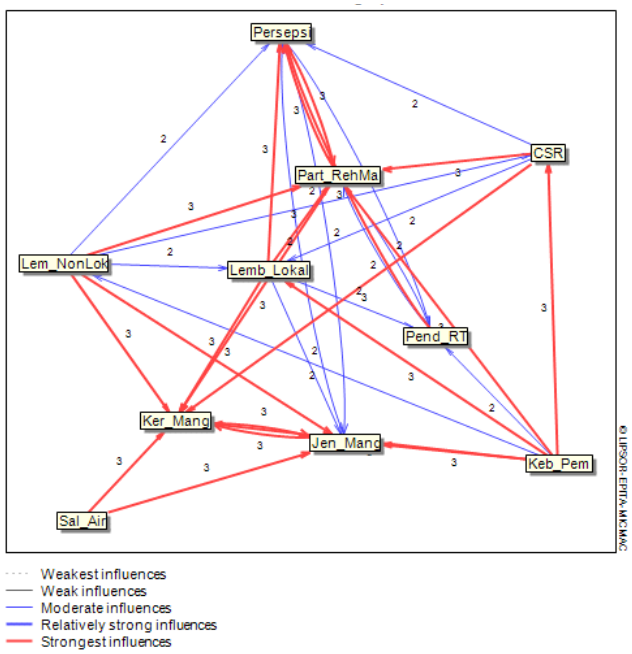

Figure 3. Network diagram showing direct influences among variables in the mangrove rehabilitation system

A notable reciprocal relationship exists between Local Institutional Support (Lemb_Lokal) and Community Participation (Part_RehMa), suggesting a mutually reinforcing dynamic that can either strengthen or weaken rehabilitation efforts. This bidirectional relationship indicates that strong local institutions enhance community participation, while active community engagement strengthens institutional legitimacy and effectiveness.

Community Participation (Part_RehMa) strongly influences Mangrove Density (Ker_Mang), establishing a clear pathway from social engagement to ecological outcomes. This relationship confirms that community involvement directly contributes to the physical success of rehabilitation efforts through activities such as planting, monitoring, and protection of mangrove areas.

The perception of mangrove benefits (Persepsi) shows moderate influence on community participation, highlighting the importance of awareness and education in motivating community action. This relationship suggests that positive perceptions of mangrove ecosystem services can enhance community willingness to participate in rehabilitation activities.

It is important to note that Figure 4 only displays the strongest relationships between variables, as the visualization was generated using a 50% threshold in the MICMAC software. This means that only connections with influence values above 50% of the maximum value are shown in the diagram. The absence of weaker relationships allows the diagram to focus on the most

significant system dynamics while maintaining visual clarity.

Indirect Influence Analysis

The MICMAC method also analyzes indirect relationships, revealing how variables influence each other through intermediary factors. This perspective is crucial for understanding long-term system dynamics. Figure 4 presents the map of indirect influences among variables.

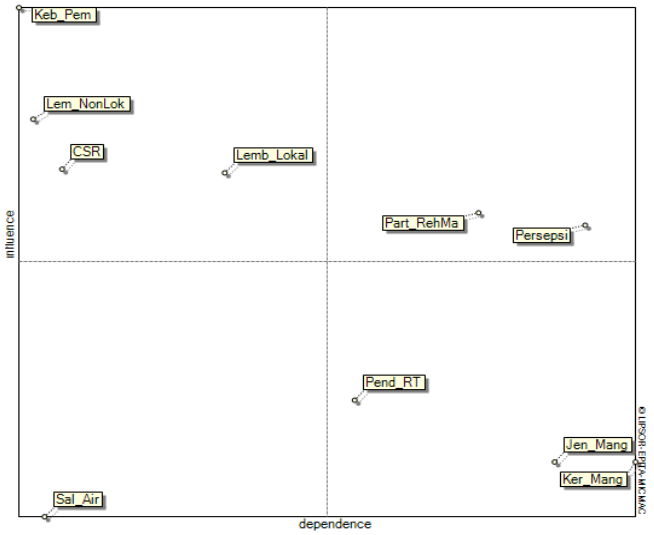

Figure 4. Influence-Dependence Map showing indirect relationships among variables in the mangrove rehabilitation system

The analysis of indirect influences reveals several important insights:

1. Government Policy (Keb_Pem) and Local Institutional Support (Lemb_Lokal) maintain their positions as key driving variables, with their influence becoming even more pronounced in the long term.
2. Community Participation (Part_RehMa) increases its strategic importance as an intermediary variable in the indirect influence map.
3. The indirect influence of Perception of Mangrove Benefits (Persepsi) on Mangrove Density (Ker_Mang) becomes more significant.
4. CSR Support (CSR) shows greater indirect influence compared to its direct influence, suggesting that while its immediate impact may be limited, its contribution to system dynamics becomes more significant over time.

Network of Indirect Influences

The network of indirect influences provides additional insights into the long-term dynamics of the mangrove rehabilitation system (Figure 5).

The indirect influence network reveals that:

1. Government Policy (Keb_Pem) has significant long-term effects on almost all system variables, including strong indirect influence on Mangrove Density (Ker_Mang).
2. The indirect influence pathways from Local Institutional Support (Lemb_Lokal) to Mangrove Density (Ker_Mang) become more pronounced, highlighting how institutional arrangements affect ecological outcomes through various intermediary mechanisms.
3. The relationship between Community Participation (Part_RehMa) and Perception of Mangrove Benefits (Persepsi) forms a stronger feedback loop in the indirect influence network, suggesting that these social factors reinforce each other over time and collectively contribute to rehabilitation outcomes.

Similar to Figure 3, Figure 5 displays only the strongest indirect relationships between variables, applying a 50% threshold in the MICMAC software. This filtering approach, as recommended by Fauzi (2019), helps to highlight the most significant pathways of influence within the complex system. The absence of weaker connections (gray lines and dotted gray lines) allows for clearer visualization of the dominant indirect influence mechanisms, making the diagram more interpretable while focusing on the relationships most relevant to policy and management decisions.

These findings highlight the complex, systemic nature of mangrove rehabilitation and emphasize the importance of considering both direct and indirect relationships when designing intervention strategies.

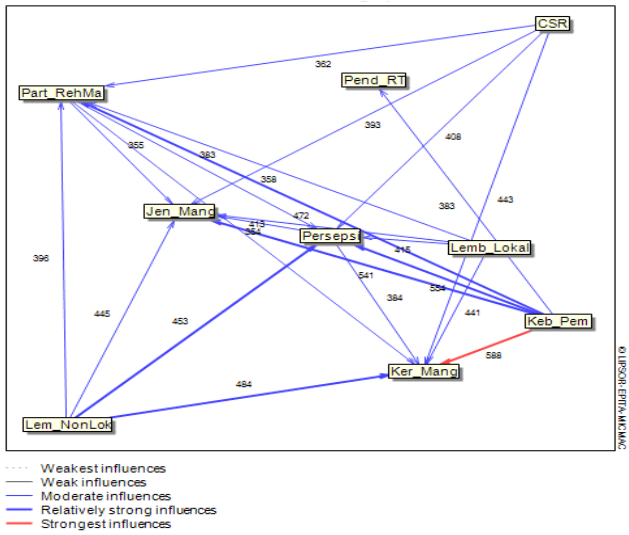

Figure 5. Network diagram showing indirect influences among variables in the mangrove rehabilitation system

Key Drivers of Mangrove Rehabilitation Succes

The MICMAC analysis identified three critical variables that significantly influence the success of mangrove rehabilitation in Ujungalang Village:

1. Government Policy (Keb_Pem): As the most influential variable in both direct and indirect analyses, government policy provides the foundational framework that enables or constrains rehabilitation efforts. This includes regulations on land use, resource allocation, coordination mechanisms, and incentive structures that shape stakeholder behavior.
2. Local Institutional Support (Lemb_Lokal): This variable emerged as a crucial mediating factor that translates policies into local action. Strong local institutions facilitate community mobilization, knowledge sharing, and adaptive management practices. The bidirectional relationship between local institutions and community participation highlights the importance of institutional capacity building as a cornerstone of sustainable rehabilitation efforts.
3. Community Participation in Rehabilitation (Part_RehMa): These variables, while positioned in the driving quadrant, showed relatively lower influence compared to government policy and local institutions. However, their classification as driving variables indicates their potential to impact the system with minimal dependence on other factors.
4. As a key relay variable, community participation both influences and is influenced by other system components. It directly affects rehabilitation outcomes while also shaping perceptions and institutional dynamics.

These findings emphasize the need for an integrated approach that simultaneously addresses policy frameworks, institutional capacity, and community engagement. By strengthening these key leverage points, rehabilitation initiatives can create positive feedback loops that enhance system performance and sustainability.

Discussion

The MICMAC analysis provides a comprehensive understanding of the factors influencing mangrove rehabilitation success in Ujungalang Village. By identifying key driving, relay, and outcome variables, this research offers valuable insights for enhancing rehabilitation effectiveness through strategic interventions.

Integrating Policy, Institutions, and Community Engagement

The emergence of Government Policy as the most influential variable underscores the critical role of policy frameworks in creating enabling conditions for mangrove rehabilitation. This finding is consistent with Jelibseda, Razak, and Diliarosta (2025), who emphasized that coherent policies combined with sustainable vegetation management are essential for long-term mangrove resilience in Riau Islands. Similar results were reported by Salahuddin, Santoso, and Hermawan (2024) in West Lombok, where local government policy directly influenced mangrove management outcomes. This finding aligns with Thompson's (2018) research highlighting how coherent policies can catalyze positive outcomes in ecosystem restoration. However, our analysis extends this understanding by demonstrating how policy influences flow through institutional and social pathways to affect ecological outcomes.

The strong bidirectional relationship between Local Institutional Support and Community Participation represents a critical feedback loop in the rehabilitation system. Evidence from Harahab and Raymond (2011) showed that community-based mangrove management in East Java could only be sustained where institutional structures were strong. Similarly, Fithria and Hidayat (2011) found that local government involvement was pivotal in Aceh Jaya for successful mangrove conservation. Similar findings were also documented by Hidayati, Santosa, and Dewi (2021) in Karimunjawa National Park, where community participation was a decisive factor in ensuring the sustainability of mangrove conservation programs. This interaction creates either virtuous or vicious cycles that can significantly affect outcomes. As Damastuti *et al*. (2022) noted, robust local institutions enhance community ownership and participation, which in turn strengthens institutional legitimacy and effectiveness. This mutual reinforcement is essential for sustaining rehabilitation efforts beyond initial implementation phases.

The positioning of Community Participation as a relay variable emphasizes its dual role as both an outcome of enabling conditions and a driver of ecological results. Yamindago's (2015) research on coastal ecosystem rehabilitation similarly identified participation as a pivotal factor that translates institutional support into tangible conservation outcomes. Our findings confirm that community engagement is not merely beneficial but necessary for rehabilitation success, particularly in contexts like Ujungalang Village where local livelihoods are closely tied to mangrove ecosystems.

The identification of External Institutional Support and CSR Support as driving variables highlights their importance in the rehabilitation system. Though they showed lower influence compared to government policy and local institutions, their classification in Quadrant I indicates their capacity to impact the system with minimal dependence on other factors. As Gazi *et al*. (2024) observed, corporate social responsibility programs can provide crucial resources and technical support that complement government efforts, especially in contexts where public funding is limited. Similarly,

Ellison *et al*. (2020) emphasized the value of external institutional partnerships in enhancing local capacity and providing specialized expertise for rehabilitation initiatives.

Biophysical Factors as System Outcomes

The analysis positions Mangrove Density and Species Diversity as output variables (Quadrant III) with high dependence on other system factors. This finding challenges simplistic approaches that focus solely on biophysical interventions without addressing underlying social and institutional dynamics. As Trialfhianty *et al*. (2022) observed, mangrove rehabilitation outcomes reflect complex interactions between ecological conditions and human systems.

Interestingly, the analysis also places Perception of Mangrove Benefits in the output quadrant, suggesting that community perceptions are significantly shaped by other system elements rather than being primary drivers themselves. A similar conclusion was reached by Ramadhani et al. (2023) who demonstrated that community perception in Balikpapan Bay was shaped more by institutional and ecological conditions than by individual attitudes. This contrasts with some literature that positions perceptions as precursors to action. However, as Bennett *et al*. (2019) noted, perceptions can be both a cause and consequence of conservation success, potentially explaining their position in our analysis. Positive environmental outcomes can reinforce positive perceptions, creating feedback loops that support continued engagement.

The relatively autonomous position of Water Salinity and Household Income in the system map (Quadrant IV) does not diminish their ecological or social importance but rather indicates that they operate somewhat independently of the main social-institutional dynamics. This suggests that while these variables should be monitored and considered in rehabilitation planning, they may not serve as primary leverage points for system-wide improvement. Sánchez-Núñez *et al*. (2023) similarly found that certain environmental variables, while important for mangrove health, may be less amenable to direct management intervention compared to social and institutional factors.

The Role of External Support and Resources

Although the analysis places External Institutional Support and CSR Support in the driving quadrant, their positioning indicates relatively lower influence compared to government policy and local institutions. Comparable findings were reported in the Philippines by Santos et al. (2022), where private sector engagement enhanced institutional performance. Internationally, Lee et al. (2021) found CSR initiatives to be significant contributors in supporting local ecological restoration projects. However, the indirect influence analysis reveals that these variables gain importance over time, particularly through their effects on local institutions and community participation. This finding is consistent with Buana and Aldin's (2024) research on the role of external partnerships in strengthening local governance capacity for coastal resource management.

The relatively low influence of Household Income contrasts with some literature that emphasizes economic factors in conservation success. This finding suggests that in the context of Ujungalang Village, socio-institutional factors may be more determinant than economic conditions alone. However, the analysis does show connections between participation, economic benefits, and perceptions, indicating that livelihood considerations remain relevant within the broader social context. This aligns with Ramli *et al*.'s (2023) findings that while economic incentives can support conservation behavior, they are often mediated by social and institutional factors.

Implications for Mangrove Rehabilitation Practice

The research findings have several important implications for improving mangrove rehabilitation practice:

1. Policy Integration and Coherence: The dominant influence of Government Policy highlights the need for integrated, cross-sectoral policy approaches that align conservation objectives with development priorities and local realities. Effective policies should provide clear regulatory frameworks while allowing sufficient flexibility for local adaptation. Lovelock and Brown (2019) emphasized that policy coherence across different governance levels is particularly crucial for addressing complex coastal management challenges.
2. Institutional Capacity Building: The strategic position of Local Institutional Support emphasizes the importance of strengthening local governance structures, enhancing technical and managerial capacities, and facilitating collaborative decision-making processes. Investments in institutional development can generate substantial returns through improved program implementation and sustainability. Damastuti *et al*. (2022) demonstrated that robust local institutions are central to translating policy intentions into effective conservation practices.
3. External Partnership Development: The identification of External Institutional Support and CSR Support as driving variables highlights the potential value of strategic partnerships with external actors. As Gazi *et al*. (2024) noted, external support can provide resources, expertise, and innovation that complement local efforts. However, our analysis suggests that such partnerships are most

effective when they strengthen rather than bypass local institutions and community processes.

4. Participatory Approaches: The identification of Community Participation as a key relay variable confirms the value of participatory approaches throughout the rehabilitation process, from planning and implementation to monitoring and evaluation. Effective participation requires not only consultation but meaningful involvement in decision-making and benefit-sharing mechanisms. Yamindago (2015) demonstrated that genuine participation enhances both the ecological effectiveness and social sustainability of coastal rehabilitation initiatives.
5. Perceptipn Management: While Perception of Mangrove Benefits emerged as an output rather than driving variable, the network analysis revealed its interconnections with participation and institutional factors. Bennett *et al.* (2019) highlighted the importance of actively managing stakeholder perceptions through education, awareness-raising, and demonstrating tangible benefits of conservation efforts.
6. System Thinking: The complex interactions revealed by the MICMAC analysis demonstrate the importance of systems thinking in rehabilitation planning. Interventions should consider both direct and indirect relationships between variables, potential feedback loops, and long-term dynamics rather than focusing on isolated factors. Manzano-Solís *et al*. (2019) similarly emphasized the value of structural systems analysis for understanding complex socio-ecological interactions in resource management contexts.

These implications align with emerging literature on social-ecological systems approaches to conservation, which emphasize the interconnected nature of environmental and social dynamics. Reinforcing this perspective, Susilo et al. (2022) highlighted that adaptive co-management is essential in Indonesian mangrove governance. Likewise, Kuenzer and Tuan (2013) in Vietnam documented that integrating social-ecological approaches improves the long-term sustainability of mangrove programs. By addressing key leverage points identified through the MICMAC analysis, rehabilitation initiatives can enhance their effectiveness and sustainability.

Limitations and Future Research Directions

While the MICMAC analysis provides valuable insights into the dynamics of mangrove rehabilitation in Ujungalang Village, some limitations should be acknowledged. The threshold visualization approach (50%) used in network diagrams (Figures 3 and 5) following Fauzi's (2019) recommendation helps to highlight key relationships but may obscure some potentially relevant secondary connections. Future studies could explore how different threshold levels affect the interpretation of system dynamics.

Additionally, the cross-sectional nature of this study captures stakeholder perceptions at a specific point in time. As Ellison *et al*. (2020) noted, adaptive management approaches require ongoing assessment of changing conditions and relationships. Longitudinal research tracking how variable relationships evolve over time would provide further insights into the dynamics of rehabilitation success.

The current analysis focused primarily on the direction and strength of relationships between variables but did not explicitly address temporal delays or non-linear effects that may be present in the system. Future research employing dynamic systems modeling techniques could complement the MICMAC approach by exploring these more complex temporal dynamics, as suggested by Sánchez-Núñez *et al*. (2023) in their study of long-term mangrove trajectories.

Furthermore, while the current study incorporated diverse stakeholder perspectives, future research could benefit from more extensive community involvement and the integration of traditional ecological knowledge, as recommended by Friess *et al*. (2024) for comprehensive mangrove conservation strategies.

Conclusion

This study employed the MICMAC method to analyze factors influencing mangrove rehabilitation success in Ujungalang Village, Indonesia, providing novel insights into complex system dynamics through stakeholder-driven analysis. The research identified four key driving variables that exert the most significant influence on the rehabilitation system: Government Policy, Local Institutional Support, External Institutional Support, and CSR Support. Government Policy emerged as the most powerful driver, demonstrating the critical role of policy frameworks in creating enabling conditions for rehabilitation success.

Community Participation in Rehabilitation functions as a crucial relay variable, creating reinforcing feedback loops with Local Institutional Support and serving as the primary pathway through which institutional and policy interventions translate into ecological outcomes. The biophysical variables (Mangrove Density and Species Diversity) and Perception of Mangrove Benefits function as output indicators, reflecting the effectiveness of the entire rehabilitation system rather than driving system behavior.

The network analysis revealed important direct and indirect relationships among variables, demonstrating how institutional and social factors shape

ecological outcomes through complex causal pathways. The visualization using a 50% threshold effectively highlighted the most significant influence mechanisms while maintaining analytical clarity. The indirect influence analysis showed that system effects compound over time, with policy and institutional interventions having increasingly important long-term impacts.

The findings provide generalizable insights for mangrove rehabilitation efforts across similar socio-ecological contexts in tropical coastal regions. The systems framework demonstrates that successful rehabilitation requires holistic approaches that simultaneously address policy coherence, institutional capacity at multiple levels, and sustained community engagement. The identification of specific variable relationships provides a template for analyzing rehabilitation systems in other locations and adapting interventions to local conditions.

The research contributes to broader understanding of social-ecological systems by demonstrating how structural analysis methods can reveal leverage points for system transformation. The finding that biophysical outcomes are primarily determined by social and institutional factors has implications beyond mangrove conservation, suggesting that ecosystem restoration efforts generally require attention to governance and social dimensions.

The practical implications include several actionable recommendations for rehabilitation practitioners and policymakers. Priority should be given to policy integration across sectors and governance levels, ensuring that mangrove rehabilitation objectives are aligned with broader development planning and supported by coherent regulatory frameworks. Institutional capacity building represents a high-impact investment area, particularly for local organizations that serve as critical intermediaries between policy frameworks and community action.

Strategic partnership development with external institutions and private sector actors should be pursued as a long-term system strengthening strategy, recognizing that these relationships may have greater impact over time than immediate visible effects. Community engagement strategies should focus on creating genuine participation opportunities while ensuring that supportive institutional and policy conditions are in place.

Monitoring and evaluation systems should track not only ecological outcomes but also the social and institutional variables identified as system drivers. This approach would enable adaptive management that responds to changes in system dynamics and ensures that interventions continue to target the most influential leverage points.

By strategically targeting these key leverage points and understanding their interconnections, rehabilitation initiatives can enhance their effectiveness and sustainability while contributing to broader goals of coastal resilience and sustainable development. The research provides both theoretical insights and practical tools for improving mangrove conservation outcomes in Indonesia and similar coastal contexts worldwide.

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Author Contributions

Laode Abdul Muluk Faathir was responsible for conceptualization, data collection, analysis, and writing. Nyoto Santoso contributed through supervision, validation, and review, while Eka Intan Kumala Putri contributed to methodology, supervision, and review.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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