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# Mangrove Conservation Model Based on Pentahelix Approach: Lesson Learned from Various Countries

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**Abstract:**

Mangrove ecosystems play a crucial role in coastal protection, biodiversity conservation, and climate change mitigation. However, their degradation due to deforestation, land conversion, and pollution remains a significant challenge. This study proposes a mangrove conservation model based on the Pentahelix approach, which integrates the collaboration of five key stakeholders: government, private sector, academia, community, and media. The model emphasizes a multi-stakeholder synergy to enhance policy implementation, sustainable economic incentives, scientific research, local engagement, and public awareness. Through qualitative analysis and case studies, this research identifies challenges such as regulatory gaps, conflicting interests, and limited community participation. The findings suggest that a well-coordinated Pentahelix framework can strengthen conservation efforts, promote sustainable livelihoods, and improve mangrove ecosystem resilience. The study concludes that effective governance, corporate responsibility, scientific contributions, community empowerment, and media advocacy are essential for the long-term sustainability of mangrove conservation.

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## INTRODUCTION

Mangrove forests are vital coastal ecosystems that provide numerous ecological, economic, and protective functions. They are highly productive and diverse, offering essential services to both local and global communities. Mangrove conservation is crucial for maintaining biodiversity, protecting coastlines, reducing carbon, providing ecosystem services, and regulating climate. Those key functions are supporting local communities in economics, social and environmental aspects (Kanjin & Alam, 2024; Li et al., 2025; Saoum & Sarkar, 2024).

Mangroves maintain biodiversity through providing a unique habitat for a wide range of terrestrial and marine species, including birds, insects, mammals, reptiles, and various aquatic organisms. They serve as nurseries for commercially important species like crabs, prawns, and fish, supporting offshore fisheries (Carugati et al., 2018; Nagelkerken et al., 2008). Furthermore, mangroves act as natural barriers against tropical cyclones and storm surges, reducing wind and wave

impacts on coastal areas (Ghosh et al., 2015; Krauss & Osland, 2020). Moreover, mangrove forests are significant carbon sinks, contributing to carbon storage and helping mitigate greenhouse gas emissions(Alongi, 2014; Lee et al., 2014; Song et al., 2024). Then, mangroves provide a range of ecosystem services, including shoreline stabilization, nutrient cycling, and supporting biodiversity. These services have substantial economic value and are essential for the livelihoods of local communities (Ball, 1988; Getzner & Islam, 2020). The last, mangroves play a role in regulating local and global climate by influencing biogeochemical processes and acting as buffers against climate change impacts like sea-level rise and increased storm frequency (Osland et al., 2017; Wang & Gu, 2021).

Mangrove ecosystems provide essential ecological, economic, and social benefits, and their functions are optimized through effective conservation and restoration efforts (Lovelock et al., 2022; Rumondang et al., 2024). Conservation strategies enhance mangrove functions such as biodiversity support, carbon storage, and coastal protection. Optimizing the functions of mangroves through conservation and restoration is vital for maintaining their ecological and economic benefits (Song et al., 2024; Su et al., 2021; Wang & Gu, 2021). Effective management strategies, community involvement, and robust policies are essential to address the challenges facing mangrove ecosystems and to enhance their role in biodiversity conservation, carbon storage, and coastal protection.

However, mangrove conservation faces numerous challenges due to both human activities and natural factors. ***First***, conflicting or unclear policy objectives at different government levels lead to contradictory management decisions, making it difficult to implement effective mangrove conservation strategies (Arifanti et al., 2022; Rumondang et al., 2024; Sofian et al., 2019). ***Second***, human activities include land-use changes such as conversion to aquaculture and agriculture, coastal development, and deforestation. These activities have historically contributed to significant mangrove degradation (Goldberg et al., 2020; Veettil et al., 2019). ***Third***, climate change such as rising sea levels, increased storm intensity, and changes in precipitation patterns pose significant threats to mangrove ecosystems (de Lacerda et al., 2019; Osland et al., 2018). ***Fourth***, large-scale restoration projects often fail, and smaller projects may not achieve landscape-scale benefits. Effective restoration requires capacity building and matching opportunities with investors (Abelson et al., 2020; Lovelock et al., 2022). ***The fifth***, inadequate policy frameworks, lack of community awareness, and insufficient regulatory actions hinder effective mangrove management. Engaging stakeholders from various sectors is essential for sustainable management (Akram et al., 2023; Arifanti et al., 2022).

This study proposes a mangrove conservation model based on the Pentahelix approach, which integrates the collaboration of five key stakeholders: government, private sector, academia, community, and media. The model emphasizes a multi-stakeholder synergy to enhance policy implementation, sustainable economic incentives, scientific research, local engagement, and public awareness.

## MATERIALS AND METHOD

The research methodology for this research is a comprehensive literature study approach. This methodology is chosen to analyze the roles of various stakeholders in the management of mangrove conservation areas. The study employs a literature study approach to gather and analyze existing information and research on the topic. This involves reviewing relevant literature to understand the current state of mangrove conservation and the roles of different stakeholders in this process. The literature study helps in identifying gaps in current practices and provides insights into how the Pentahelix model can be effectively applied.

A significant part of the methodology is the analysis of stakeholder roles. The study examines how each actor within the Penta Helix model contributes to mangrove conservation. It identifies the inconsistencies in state rules and the limited involvement of the private sector in coastal preservation. This analysis is crucial for understanding the dynamics of stakeholder interactions and the effectiveness of current policies.

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## RESULTS AND DISCUSSION

The Pentahelix model is a collaborative framework that underscores the active involvement of five primary stakeholder groups. These include academics, researchers, government institutions, media actors, and local communities. Each group plays a critical role in fostering innovation, policy development, and sustainable implementation. The integration of these stakeholders enhances multi-sectoral synergy and promotes more effective, inclusive outcomes.

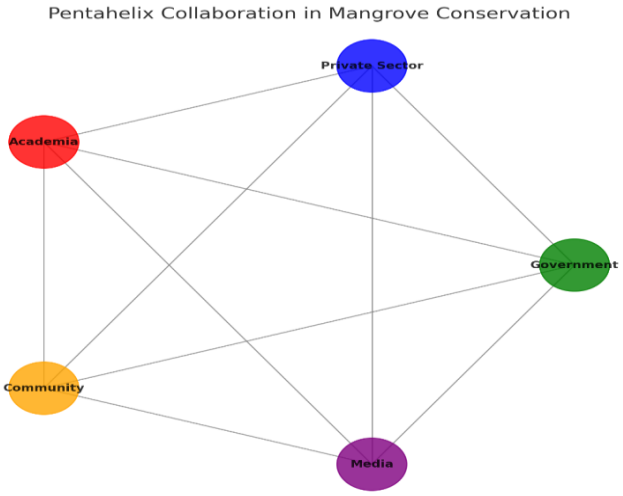


**Figure 1.** Pentahelix Collaboration

The Pentahelix model emphasizes the involvement of five key stakeholder groups: academics, researchers, government, media, and communities. Each group plays a vital role in sustainable mangrove conservation. Academics and researchers contribute through studies and data that inform conservation strategies. The government is responsible for creating and enforcing policies, although there is a noted inconsistency in policy implementation that needs addressing. Media helps in raising awareness and educating the public about the importance of mangrove conservation. Communities are crucial for on-the-ground conservation efforts and ensuring that local needs and knowledge are integrated into management plans (Lewenussa, 2023).

### Lesson Learned on Mangrove Conservation

### The Role of Government

**Policy Formulation**. Mangrove conservation policies are often fragmented due to the involvement of multiple sectors and institutional structures. In Southeast Asia, countries like Indonesia, Thailand, and the Philippines have numerous laws and institutions governing mangrove protection, yet the application of these rules varies significantly (Friess et al., 2016; Susilo et al., 2023). In Panama, despite having multiple policies targeting mangroves, implementation is hindered by competing governmental agendas (Chamberland-Fontaine et al., 2022). Brazil has seen a weakening of legal frameworks protecting mangroves, which poses a risk to these ecosystems (Bernardino et al., 2021; Ottoni et al., 2021).

**Enforcement**. Enforcement of mangrove conservation laws is a critical challenge. In Southeast Asia, conflicting policy objectives at different government levels lead to contradictory management decisions, complicating enforcement efforts (Friess et al., 2016). In Panama, policy implementation gaps are exacerbated by institutional structures that fail to include local communities effectively (Chamberland-Fontaine et al., 2022). In Brazil, the promotion of economic activities such as shrimp farming in mangrove ecosystems exacerbates challenges in law enforcement and environmental conservation.The expansion of shrimp aquaculture in Brazilian mangrove regions weakens regulatory enforcement, further threatening the ecological integrity of these vital coastal habitats (Ottoni et al., 2021).

**Financial Support**. Financial mechanisms such as Payments for Ecosystem Services (PES) are promising for mangrove conservation. These schemes, particularly carbon PES (blue carbon), are gaining attention but face implementation barriers (Friess et al., 2016). In Indonesia, integrating mangrove management with national climate commitments is a priority, requiring substantial financial investment and stakeholder involvement (Arifanti et al., 2022). Globally, the need for coordinated financial support across forestry, wetland, and integrated coastal zone management programs is emphasized to sustain mangrove ecosystems (Carter et al., 2015).

### Challenges and Future Directions.

The main challenges in mangrove conservation include policy fragmentation, inadequate enforcement, and insufficient financial

support. Addressing these requires a multi-disciplinary approach, involving community engagement, policy realignment, and long-term project funding (Lovelock & Brown, 2019). Future strategies should focus on harmonizing policies across jurisdictions, enhancing community participation, and leveraging international cooperation to strengthen mangrove management (Bell-James et al., 2020; Carter et al., 2015).

## Academics Perspectives

**Research and Policy Formulation:** Scholars play a crucial role in establishing theoretical frameworks and shaping policies to support mangrove conservation efforts. In Niger Delta, Nigeria, research highlighted the need for participatory frameworks and community involvement in conservation efforts, which were previously lacking (Onyena & Sam, 2020). Similarly, in Southeast Asia, academic studies have informed the development of conservation policies, emphasizing the need for integrated approaches that consider both ecological and social factors (Gerona-Daga & Salmo, 2022; Susilo et al., 2023).

**Historical and Ecological Studies**. In Latin America, historical ecology studies have provided baselines for understanding mangrove dynamics and informing conservation strategies. These studies have shown that despite legal protections, mangrove cover continues to decline due to human activities, underscoring the need for effective management strategies (López-Angarita et al., 2016). In Vietnam, research has focused on the historical development and current state of mangroves, highlighting successful co-management models for restoration (Veettil et al., 2019).

**Restoration Techniques and Success**. In Colombia, academic research has documented various restoration techniques and their relative success, emphasizing community-based ecological restoration as the most effective approach (Rodríguez-Rodríguez et al., 2021). A meta-analysis of global restoration efforts highlights the ecological and economic benefits of restored mangroves. These benefits include enhanced biodiversity, coastal protection, and increased carbon sequestration. However, the effectiveness of restoration varies significantly across different projects. This variability is largely influenced by the restoration methods employed and site-specific environmental conditions (Su et al., 2021).

## Challenges and Future Directions.

**Socio-Economic and Legal Challenges**. Mangrove conservation faces challenges related to socio-economic contexts and legal frameworks. In Brazil, the lack of integrated social-ecological data and the influence of socio-economic factors on conservation policies have been identified as significant challenges (Borges et al., 2017). In Southeast Asia, the complexity of legal frameworks and institutional arrangements poses additional hurdles (Susilo et al., 2023).

**Governance and Stakeholder Involvement**. Effective governance is crucial for successful mangrove conservation. Studies have shown that principles of good governance, such as legitimacy, fairness, and stakeholder integration, are vital for conservation success. Transparent communication and clearly defined roles for all stakeholders are recommended to enhance governance outcomes (Golebie et al., 2022).

**Transdisciplinary Approaches**. In the Philippines, a transdisciplinary approach involving academics, NGOs, and local communities has been successful in addressing the conversion of mangroves to aquaculture. This approach emphasizes the importance of ecological economics and stakeholder collaboration in developing sustainable solutions (Farley et al., 2010). In conclusion, academics play a pivotal role in mangrove conservation by conducting research that informs policy, developing effective restoration techniques, and advocating for inclusive governance. Lessons from various countries highlight the importance of integrating ecological and socio-economic factors, involving local communities, and adopting transdisciplinary approaches to address the complex challenges of mangrove conservation.

## Private Sector Perspectives

**Private Sector Initiatives**. Private sector involvement in mangrove conservation can take various forms, including direct investment in restoration projects and the development of novel conservation mechanisms. In Southeast Asia, private-sector initiatives have been identified as a

potential means to protect mangroves, especially in degraded areas or those under threat. These initiatives can complement government efforts and help bridge policy gaps (Friess et al., 2016). Additionally, the private sector can engage in carbon payment schemes, such as blue carbon projects, which offer financial incentives for conservation (Friess et al., 2016).

**Community-Based Management and Private Sector Collaboration.** Community-based management models have shown promise in mangrove conservation, particularly when supported by private sector partnerships. In Mozambique, community-driven efforts to restore mangroves have been bolstered by introducing alternative income-generating activities, which can be supported by private investments. Similarly, in Colombia, community-based ecological mangrove restoration has been identified as one of the most effective restoration types, suggesting that private sector support in these initiatives could enhance their success (Rodríguez-Rodríguez et al., 2021).

**Challenges and Opportunities.** Despite the potential benefits, challenges remain in effectively integrating private sector roles in mangrove conservation. These include ensuring fair and transparent governance, aligning private sector goals with conservation objectives, and overcoming barriers to implementing payment for ecosystem services (PES) schemes6 2. However, opportunities exist in leveraging private sector resources for large-scale restoration projects and in developing innovative conservation financing mechanisms3 9. To conclude, the involvement of the private sector in mangrove conservation offers significant potential to enhance restoration and protection efforts. By learning from international experiences, countries can develop strategies that effectively integrate private sector roles, ensuring sustainable management of these critical ecosystems.

## Community Participation

**Community Participation and Empowerment**. Successful mangrove conservation projects emphasize the need for meaningful community participation. In Madagascar, empowering communities to take a leading role from the early stages of project design has been crucial. This includes careful scheduling of meetings to avoid fatigue, using anonymous democratic votes to ensure inclusivity, and creating spaces for women to participate in decision-making (Ravaoarinorotsihoarana et al., 2023). Similarly, in West Kalimantan, a bottom-up approach has been implemented to engage communities in planning, implementation, and evaluation processes. This participatory model has proven to be effective in fostering local ownership and sustainability. However, the degree of community involvement is not uniform across all individuals. Variations in participation levels may be influenced by factors such as awareness, capacity, and socio-cultural dynamics (Roslinda et al., 2021).

**Community Involvement**. Successful Community-based mangrove management (CBMM) initiatives often involve strong community participation, where local norms and management plans are developed by community committees, such as the Natural Resources Management Committee in Mozambique (Macamo et al., 2024). In Thailand, community leadership and the ability to organize into groups have been crucial for the success of CBMM (Kongkeaw et al., 2019). In Indonesia, the effectiveness of CBMM varied across villages, with differences in community participation and external support affecting outcomes (Damastuti & de Groot, 2017).

## Challenges and Recommendations

**Enforcement and Resource Limitations**. A common challenge in CBMM is the enforcement of regulations and exclusion of illegal activities due to resource limitations. This has been observed in Mozambique, where more government involvement is needed to enhance law enforcement (Macamo et al., 2024). In the Philippines, unclear access and utilization rights have posed challenges, highlighting the need for clear policies and community rights over mangrove resources (Pulhin et al., 2017).

**Institutional and Socio-Political Factors**. Institutional sustainability requires restructuring CBMM institutions to ensure participation of all community members in decision-making and resource sharing (Datta et al., 2012). The success of CBMM in Thailand has been attributed to the support from NGOs and government, indicating the importance of external support in the initial and

subsequent phases of CBMM (Kongkeaw et al., 2019).

## Future Directions

**Integration of Scientific and Technological Assistance**. Combining local management strategies with external scientific and technological assistance can improve CBMM performance. This includes income diversification, institutional reinforcement, and continuous monitoring (Damastuti & de Groot, 2017). In Mexico, the transition from mangrove plantations to hydrological restoration and community capacity building has proven to be more effective for long-term ecosystem rehabilitation. Hydrological restoration addresses the root causes of mangrove degradation by reestablishing natural water flows. Simultaneously, capacity building empowers local communities to manage and protect restored ecosystems sustainably. This integrated approach enhances ecological resilience and ensures lasting environmental and socio-economic benefits (Zaldívar-Jiménez et al., 2017).

**Sustainability and Adaptation**. Evaluating the sustainability of CBMM using criteria and indicators contextual to the area is crucial. This includes adapting management practices to the physical, cultural, and socio-economic conditions of the location (Buncag, 2021). In the context of climate change, fostering climate-resilient communities through CBMM is essential, as seen in the Philippine (Pulhin et al., 2017). In conclusion, community-based mangrove management offers a promising approach to sustainably manage mangrove resources while supporting local livelihoods. However, challenges such as enforcement, institutional sustainability, and socio-political factors need to be addressed through comprehensive strategies that integrate community participation, economic support, and external assistance.

## The Role of Media

**Influencing Public Perception**: Media, particularly social media platforms like Twitter, Facebook, and Instagram, can effectively raise awareness about the importance of mangroves. By sharing images and stories, media can influence public perceptions and encourage positive conservation actions (Dahdouh-Guebas et al., 2020). **Highlighting Ecosystem Benefits**: Mangroves provide essential services such as shoreline protection, fisheries support, carbon capture, and biodiversity conservation. Media can help highlight these benefits, making a case for their conservation (Dahdouh-Guebas et al., 2020). **Under-Recognition**: Mangroves play a critical role in coastal protection, biodiversity support, and carbon sequestration. However, they remain significantly underrepresented in media narratives when compared to ecosystems such as coral reefs. This disparity in coverage may contribute to lower public awareness and weaker conservation prioritization. Enhancing media attention on mangroves could foster greater public engagement and strengthen efforts toward their preservation (Dahdouh-Guebas et al., 2020).

## Future Directions

**Increased Media Coverage**: There is a need for more focused media campaigns to raise awareness about the critical role of mangroves in ecosystem services and biodiversity conservation. **Utilizing Social Media**: Leveraging social media platforms to share compelling stories and visuals of mangrove ecosystems can engage a broader audience and foster community-driven conservation initiatives. **Educational Campaigns**: Developing educational content that highlights the unique adaptations and ecological roles of mangroves can enhance public understanding and support for conservation efforts.

## Challenges on Mangrove Conservation

The Penta helix Approach involves five key stakeholders—government, private sector, academia, communities, and media—working together to address complex environmental challenges like mangrove conservation. Despite its integrative framework, several challenges arise in its implementation:

## Government Challenges

**Lack of Clear Regulations:** Policies may be fragmented or weakly enforced, leading to inconsistent protection efforts and ineffective conservation outcomes. **Bureaucratic Barriers:** Overlapping authorities between national and local

governments can slow down decision-making, creating inefficiencies in policy implementation. **Limited Funding:** Budget constraints affect reforestation, enforcement, and monitoring efforts, making it difficult to sustain long-term environmental programs. Lack of Public Awareness: Insufficient education and outreach initiatives result in low community engagement, reducing support for conservation and sustainability efforts.

**Private Sector Challenges**

**Profit-Driven Interests**: Companies may prioritize short-term economic gains over long-term sustainability. **Corporate Greenwashing**: Some businesses engage in conservation efforts for branding without genuine environmental commitment. **Limited Incentives**: There may be a lack of financial or regulatory benefits to encourage mangrove-friendly practices.

**Academic Challenges**

**Research-Implementation Gap**: Scientific findings often do not translate directly into policy or practical conservation actions. **Funding for Research**: Limited financial support for long-term ecological studies and monitoring programs. **Low Public Engagement**: Research may not be easily accessible or communicated effectively to non-experts.

**Community Challenges**

**Conflicting Livelihood Needs:** Many local communities rely on mangroves for fishing, firewood, or land conversion for agriculture and aquaculture, creating a challenge between conservation and economic survival. **Lack of Awareness:** Limited knowledge about the ecological benefits of mangroves leads to continued exploitation, as communities may not fully understand their long-term value. **Resistance to Change:** Traditional practices and economic dependencies can hinder conservation adoption, making it difficult to implement sustainable alternatives. Inadequate Support Systems: A lack of incentives, alternative livelihoods, and policy enforcement further discourages communities from shifting towards sustainable mangrove management.

**Media Challenges**

**Lack of Coverage:** Environmental issues often take a backseat to more immediate political or economic news, reducing public urgency for action. Misinformation: Inaccurate reporting or biased narratives can mislead the public about conservation efforts, hindering informed decision-making. **Limited Reach:** Awareness campaigns often fail to effectively reach rural or marginalized communities. As a result, critical stakeholders may remain uninformed or disengaged. This communication gap can hinder the success of development programs and policy implementation. Therefore, tailored strategies are needed to ensure inclusive and equitable dissemination of information.**Weak Media Engagement:** A lack of collaboration between environmental organizations and media outlets can hinder the effective communication of environmental issues. Without strategic partnerships, storytelling may lack depth, accuracy, or resonance with the public. This can lead to narratives that fail to capture the urgency or relevance of environmental challenges. Consequently, public awareness and motivation to take meaningful action may remain limited.

**Table 1.** The Role of Pentahelix stakeholders

| Stakeholders | Description | Roles |
|---|---|---|
| Government | Acts as a policymaker and regulator, providing support and frameworks for initiatives. | • Formulation of Policies: Governments create policies, laws, and regulations to protect mangroves, such as zoning laws, protected area designations, and bans on destructive activities.<br>• Enforcement: The government ensures compliance with conservation regulations through monitoring, penalties, and law enforcement.<br>• Financial Support: Funding for Conservation Programs and Incentives for Private Sector Involvement |

| | | |
|---|---|---|
| Academics | Contribute through research, development, and conceptualization of strategies and solutions. | • Research and Analysis: Academics conduct in-depth studies to understand the challenges and opportunities in mangrove management (Arifanti et al., 2022).<br>• Policy Development: Research highlights the importance of integrating mangroves into marine protected areas and developing policies that reconcile conflicting objectives across government tiers (Friess et al., 2016).<br>• Conservation Prioritization: Academics use species distribution models to identify priority areas and species for conservation, helping to guide decision-making and resource allocation in regions with rich mangrove diversity (Banerjee et al., 2022). |
| Private Sector | Engages in investment and development, providing resources and innovation. | • Policy Integration: Successful mangrove conservation requires integrating private sector efforts with national and local policies to ensure cohesive management strategies (Borges et al., 2017; Golebie et al., 2022).<br>• Stakeholder Engagement: Effective conservation involves engaging all stakeholders, including local communities, governments, and private entities, to ensure that conservation efforts are inclusive and sustainable (Golebie et al., 2022; Roy, 2016).<br>• Monitoring and Evaluation: Long-term monitoring systems, such as Mexico's Mangrove Monitoring System, can provide valuable data to guide private sector investments and improve restoration outcomes (Rodríguez-Zúñiga et al., 2022). |
| Community | Participates actively, providing local insights and support for initiatives. | • Community-Based Tourism: Local communities can engage in community-based tourism, which not only raises awareness about the importance of mangroves but also provides economic benefits. This model has been successful in increasing community knowledge about mangrove biology and ecology, leading to better conservation and restoration efforts1.<br>• Participatory Frameworks: Effective mangrove conservation requires participatory frameworks that involve local communities in decision-making processes. This includes recognizing indigenous knowledge and ensuring that community members are seen as partners in conservation efforts (Ntibona et al., 2023; Onyena & Sam, 2020).<br>• Economic Incentives and Livelihoods. Economic benefits and livelihood opportunities are significant motivators for community participation in mangrove conservation. Communities are more likely to engage in conservation activities when they see direct economic benefits, such as the sustainable exploitation of mangrove resources (Aheto et al., 2016; Fathyyah Zulfa Maulidah et al., 2023).<br>• Education and Awareness: Increasing awareness and education about the ecological and economic importance of mangroves can drive community participation. Factors such as the age, education level, and income sources of community members influence their willingness to participate in conservation activities (Ntibona et al., 2023).<br>• Institutional Support and Co-Management: Establishing co-management frameworks and restructuring community-based management institutions to include diverse community members in decision-making can enhance the sustainability of conservation |

| | | |
|---|---|---|
| | | efforts. This includes ensuring equitable distribution of benefits among community members (Datta et al., 2012). |
| Media | Acts as a catalyst, promoting initiatives and ensuring information dissemination. | • Influencing Public Perception: Social media platforms like Twitter, Facebook, and Instagram have been effective in raising awareness about the urgency of conserving ecosystems, including mangroves. Sharing images and information about mangroves can help shift public perception and encourage conservation actions (Dahdouh-Guebas et al., 2020).<br>• Educational Media: Developing educational media, such as learning videos, has proven effective in increasing awareness and understanding of mangrove ecosystems. In Indonesia, educational videos about mangroves have been validated as effective tools for learning, enhancing both cognitive and affective understanding among students (Daningsih et al., 2023). |

**Source:** Related Articles, 2025

## CONCLUSION

The Pentahelix model provides a comprehensive framework for mangrove conservation by integrating diverse stakeholder roles. Addressing policy inconsistencies and enhancing community involvement are critical steps towards achieving sustainable mangrove ecotourism and conservation. **Governments** are pivotal in mangrove conservation through policy-making, regulation, and collaboration with stakeholders. Effective governance requires clear policies, community involvement, and addressing socioeconomic challenges to ensure the sustainable management of mangrove ecosystems. These efforts not only protect biodiversity but also contribute to climate change mitigation and the resilience of coastal communities. **Academics** significantly contribute to mangrove conservation through education, research, and collaboration with various stakeholders. Their efforts help raise awareness, develop sustainable management practices, and influence policy-making, ultimately supporting the preservation and restoration of these vital ecosystems. Furthermore, **the private sector's** involvement in mangrove conservation is vital for addressing the large-scale challenges these ecosystems face. Through protection initiatives and participation in PES schemes, private entities can significantly contribute to the sustainable management and conservation of mangroves, supporting both biodiversity and local livelihoods. **Community participation** is vital for the successful conservation of mangrove ecosystems. By understanding the factors that influence participation, recognizing the benefits of involvement, and implementing effective strategies, conservation efforts can be enhanced, ultimately benefiting both the environment and local communities. Moreover, **the role of media** in mangrove conservation is crucial for raising awareness and driving conservation efforts. Lessons from various countries highlight the importance of media in influencing public perceptions and promoting conservation actions.

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## AUTHOR CONTRIBUTIONS

All authors collaborated in conducting each stage of the research and manuscript writing.

## CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

## REFERENCES

Abelson, A., Reed, D. C., Edgar, G. J., Smith, C. S., Kendrick, G. A., Orth, R. J., Airoldi, L., Silliman, B., Beck, M. W., Krause, G., Shashar, N., Stambler, N., & Nelson, P. (2020). Challenges for Restoration of Coastal Marine Ecosystems in the Anthropocene. In Frontiers in Marine Science (Vol. 7). https://doi.org/10.3389/fmars.2020.544105

Aheto, D. W., Kankam, S., Okyere, I., Mensah, E., Osman, A., Jonah, F. E., & Mensah, J. C. (2016). Community-

based mangrove forest management: Implications for local livelihoods and coastal resource conservation along the Volta estuary catchment area of Ghana. Ocean and Coastal Management, 127. https://doi.org/10.1016/j.ocecoaman.2016.04.006

Akram, H., Hussain, S., Mazumdar, P., Chua, K. O., Butt, T. E., & Harikrishna, J. A. (2023). Mangrove Health: A Review of Functions, Threats, and Challenges Associated with Mangrove Management Practices. In Forests (Vol. 14, Issue 9). https://doi.org/10.3390/f14091698

Alongi, D. M. (2014). Carbon cycling and storage in mangrove forests. Annual Review of Marine Science, 6. https://doi.org/10.1146/annurev-marine-010213-135020

Arifanti, V. B., Sidik, F., Mulyanto, B., Susilowati, A., Wahyuni, T., Subarno, Yulianti, Yuniarti, N., Aminah, A., Suita, E., Karlina, E., Suharti, S., Pratiwi, Turjaman, M., Hidayat, A., Rachmat, H. H., Imanuddin, R., Yeny, I., Darwiati, W., … Novita, N. (2022). Challenges and Strategies for Sustainable Mangrove Management in Indonesia: A Review. In Forests (Vol. 13, Issue 5). https://doi.org/10.3390/f13050695

Ball, M. C. (1988). Ecophysiology of mangroves. In Trees (Vol. 2, Issue 3). https://doi.org/10.1007/BF00196018

Banerjee, A. K., Feng, H., Lin, Y., Liang, X., Wang, J., & Huang, Y. (2022). Setting the priorities straight - Species distribution models assist to prioritize conservation targets for the mangroves. Science of the Total Environment, 806. https://doi.org/10.1016/j.scitotenv.2021.150937

Bell-James, J., Boardman, T., & Foster, R. (2020). Can't see the (mangrove) forest for the trees: Trends in the legal and policy recognition of mangrove and coastal wetland ecosystem services in Australia. Ecosystem Services, 45. https://doi.org/10.1016/j.ecoser.2020.101148

Bernardino, A. F., Nóbrega, G. N., & Ferreira, T. O. (2021). Consequences of terminating mangrove's protection in Brazil. Marine Policy, 125. https://doi.org/10.1016/j.marpol.2020.104389

Borges, R., Ferreira, A. C., & Lacerda, L. D. (2017). Systematic planning and ecosystem-based management as strategies to reconcile mangrove conservation with resource use. In Frontiers in Marine Science (Vol. 4, Issue NOV). https://doi.org/10.3389/fmars.2017.00353

Buncag, M. J. J. (2021). Community-based mangrove forest management sustainability: The case of some Asian countries. International Journal of Science and Research (IJSR), 10(4).

Carter, H. N., Schmidt, S. W., & Hirons, A. C. (2015). An international assessment of mangrove management: Incorporation in integrated coastal zone management. In Diversity (Vol. 7, Issue 2). https://doi.org/10.3390/d7020074

Carugati, L., Gatto, B., Rastelli, E., Lo Martire, M., Coral, C., Greco, S., & Danovaro, R. (2018). Impact of mangrove forests degradation on biodiversity and ecosystem functioning. Scientific Reports, 8(1). https://doi.org/10.1038/s41598-018-31683-0

Chamberland-Fontaine, S., Heckadon-Moreno, S., & Hickey, G. M. (2022). Tangled Roots and Murky Waters: Piecing Together Panama's Mangrove Policy Puzzle. Frontiers in Forests and Global Change, 5. https://doi.org/10.3389/ffgc.2022.818722

Dahdouh-Guebas, F., Ajonina, G. N., Amir, A. A., Andradi-Brown, D. A., Aziz, I., Balke, T., Barbier, E. B., Cannicci, S., Cragg, S. M., Cunha-Lignon, M., Curnick, D. J., Duarte, C. M., Duke, N. C., Endsor, C., Fratini, S., Feller, I. C., Fromard, F., Hugé, J., Huxham, M., … Friess, D. A. (2020). Public Perceptions of Mangrove Forests Matter for Their Conservation. Frontiers in Marine Science, 7. https://doi.org/10.3389/fmars.2020.603651

Damastuti, E., & de Groot, R. (2017). Effectiveness of community-based mangrove management for sustainable resource use and livelihood support: A case study of four villages in Central Java, Indonesia. Journal of Environmental Management, 203. https://doi.org/10.1016/j.jenvman.2017.07.025

Daningsih, E., Ramadhan, R., & Da Costa, Y. O. (2023). Development of Learning Video: Mangroves and Phytoplankton in Batu Ampar, West Kalimantan. BIOEDUSCIENCE, 7(3). https://doi.org/10.22236/jbes/11278

Datta, D., Chattopadhyay, R. N., & Guha, P. (2012). Community based mangrove management: A review on status and sustainability. In Journal of Environmental Management (Vol. 107). https://doi.org/10.1016/j.jenvman.2012.04.013

de Lacerda, L. D., Borges, R., & Ferreira, A. C. (2019). Neotropical mangroves: Conservation and sustainable use in a scenario of global climate change. In Aquatic Conservation: Marine and Freshwater Ecosystems (Vol. 29, Issue 8). https://doi.org/10.1002/aqc.3119

Farley, J., Batker, D., De La Torre, I., & Hudspeth, T. (2010). Conserving mangrove ecosystems in the Philippines: Transcending disciplinary and institutional borders. Environmental Management, 45(1). https://doi.org/10.1007/s00267-009-9379-4

Fathyyah Zulfa Maulidah, Johan Iskandar, & Budhi Gunawan. (2023). The Tangible and Intangible Benefits of Mangrove Forests as a Factor Affecting Community Participation in Mangrove Management. Journal of Tropical Ethnobiology, 6(2). https://doi.org/10.46359/jte.v6i2.174

Friess, D. A., Thompson, B. S., Brown, B., Amir, A. A., Cameron, C., Koldewey, H. J., Sasmito, S. D., & Sidik, F. (2016). Policy challenges and approaches for the conservation of mangrove forests in Southeast Asia. Conservation Biology : The Journal of the Society for Conservation Biology, 30(5). https://doi.org/10.1111/cobi.12784

Gerona-Daga, M. E. B., & Salmo, S. G. (2022). A systematic review of mangrove restoration studies in Southeast Asia: Challenges and opportunities for the United

Nation's Decade on Ecosystem Restoration. In Frontiers in Marine Science (Vol. 9). https://doi.org/10.3389/fmars.2022.987737

Getzner, M., & Islam, M. S. (2020). Ecosystem services of mangrove forests: Results of a meta-analysis of economic values. International Journal of Environmental Research and Public Health, 17(16). https://doi.org/10.3390/ijerph17165830

Ghosh, A., Schmidt, S., Fickert, T., & Nüsser, M. (2015). The Indian Sundarban mangrove forests: History, utilization, conservation strategies and local perception. Diversity, 7(2). https://doi.org/10.3390/d7020149

Goldberg, L., Lagomasino, D., Thomas, N., & Fatoyinbo, T. (2020). Global declines in human-driven mangrove loss. Global Change Biology, 26(10). https://doi.org/10.1111/gcb.15275

Golebie, E. J., Aczel, M., Bukoski, J. J., Chau, S., Ramirez-Bullon, N., Gong, M., & Teller, N. (2022). A qualitative systematic review of governance principles for mangrove conservation. In Conservation Biology (Vol. 36, Issue 1). https://doi.org/10.1111/cobi.13850

Kanjin, K., & Alam, B. M. (2024). Assessing changes in land cover, NDVI, and LST in the Sundarbans mangrove forest in Bangladesh and India: A GIS and remote sensing approach. Remote Sensing Applications: Society and Environment, 36, 101289. https://doi.org/10.1016/j.rsase.2024.101289

Kongkeaw, C., Kittitornkool, J., Vandergeest, P., & Kittiwatanawong, K. (2019). Explaining success in community based mangrove management: Four coastal communities along the Andaman Sea, Thailand. Ocean and Coastal Management, 178. https://doi.org/10.1016/j.ocecoaman.2019.104822

Krauss, K. W., & Osland, M. J. (2020). Tropical cyclones and the organization of mangrove forests: A review. In Annals of Botany (Vol. 125, Issue 2). https://doi.org/10.1093/aob/mcz161

Lee, S. Y., Primavera, J. H., Dahdouh-Guebas, F., Mckee, K., Bosire, J. O., Cannicci, S., Diele, K., Fromard, F., Koedam, N., Marchand, C., Mendelssohn, I., Mukherjee, N., & Record, S. (2014). Ecological role and services of tropical mangrove ecosystems: A reassessment. Global Ecology and Biogeography, 23(7). https://doi.org/10.1111/geb.12155

Lewenussa, R. (2023). Sustainable Mangrove Ecotourism Management Strategy in the Penta Helix Model (Literature Study) in Sorong City, West Papua Province. https://doi.org/10.2991/978-94-6463-146-3_10

Li, B., Xia, Y., Chen, X., Wang, J., Liu, W., Wang, Z., ... & Ren, H. (2025). Enhanced sediment microbial diversity in mangrove forests: Indicators of nutrient status in coastal ecosystems. Marine Pollution Bulletin, 211, 117421. https://doi.org/10.1016/j.marpolbul.2024.117421

López-Angarita, J., Roberts, C. M., Tilley, A., Hawkins, J. P., & Cooke, R. G. (2016). Mangroves and people: Lessons from a history of use and abuse in four Latin American countries. In Forest Ecology and Management (Vol. 368). https://doi.org/10.1016/j.foreco.2016.03.020

Lovelock, C. E., & Brown, B. M. (2019). Land tenure considerations are key to successful mangrove restoration. In Nature Ecology and Evolution (Vol. 3, Issue 8). https://doi.org/10.1038/s41559-019-0942-y

Lovelock, C. E., Barbier, E., & Duarte, C. M. (2022). Tackling the mangrove restoration challenge. PLoS Biology, 20(10). https://doi.org/10.1371/journal.pbio.3001836

Macamo, C. da C. F., Inácio da Costa, F., Bandeira, S., Adams, J. B., & Balidy, H. J. (2024). Mangrove community-based management in Eastern Africa: experiences from rural Mozambique. Frontiers in Marine Science, 11. https://doi.org/10.3389/fmars.2024.1337678

Nagelkerken, I., Blaber, S. J. M., Bouillon, S., Green, P., Haywood, M., Kirton, L. G., Meynecke, J. O., Pawlik, J., Penrose, H. M., Sasekumar, A., & Somerfield, P. J. (2008). The habitat function of mangroves for terrestrial and marine fauna: A review. In Aquatic Botany (Vol. 89, Issue 2). https://doi.org/10.1016/j.aquabot.2007.12.007

Ntibona, L. N., Shalli, M. S., & Mangora, M. M. (2023). Willingness and drivers of community participation in mangrove conservation in the Rufiji Delta, Tanzania. Western Indian Ocean Journal of Marine Science, 22(1). https://doi.org/10.4314/wiojms.v22i1.4

Onyena, A. P., & Sam, K. (2020). A review of the threat of oil exploitation to mangrove ecosystem: Insights from Niger Delta, Nigeria. In Global Ecology and Conservation (Vol. 22). https://doi.org/10.1016/j.gecco.2020.e00961

Osland, M. J., Feher, L. C., Griffith, K. T., Cavanaugh, K. C., Enwright, N. M., Day, R. H., Stagg, C. L., Krauss, K. W., Howard, R. J., Grace, J. B., & Rogers, K. (2017). Climatic controls on the global distribution, abundance, and species richness of mangrove forests. Ecological Monographs, 87(2). https://doi.org/10.1002/ecm.1248

Osland, M. J., Feher, L. C., López-Portillo, J., Day, R. H., Suman, D. O., Guzmán Menéndez, J. M., & Rivera-Monroy, V. H. (2018). Mangrove forests in a rapidly changing world: Global change impacts and conservation opportunities along the Gulf of Mexico coast. Estuarine, Coastal and Shelf Science, 214. https://doi.org/10.1016/j.ecss.2018.09.006

Ottoni, F. P., Hughes, R. M., Katz, A. M., Rangel-Pereira, F. da S., de Bragança, P. H. N., Fernandes, R., Palmeira-Nunes, A. R. O., Nunes, J. L. S., Dos Santos, R. R., Piorski, N. M., & Rodrigues-Filho, J. L. (2021). Brazilian mangroves at risk. Biota Neotropica, 21(2). https://doi.org/10.1590/1676-0611-bn-2020-1172

Pulhin, J. M., Gevaña, D. T., & Pulhin, F. B. (2017). Community-Based Mangrove Management in the Philippines: Experience and Challenges in the Context of Changing Climate. https://doi.org/10.1007/978-4-431-56481-2_16

Ravaoarinorotsihoarana, L. A., Maltby, J., Glass, L., Oates, J., Rakotomahazo, C., Randrianandrasaziky, D. A., Ranivoarivelo, L. N., & Lavitra, T. (2023). Lessons for

ensuring continued community participation in a mangrove blue carbon conservation and restoration project in Madagascar. Western Indian Ocean Journal of Marine Science, 22(2). https://doi.org/10.4314/WIOJMS.V22I2.4

Rodríguez-Rodríguez, J. A., Mancera-Pineda, J. E., & Tavera, H. (2021). Mangrove restoration in Colombia: Trends and lessons learned. Forest Ecology and Management, 496. https://doi.org/10.1016/j.foreco.2021.119414

Rodríguez-Zúñiga, M. T., Troche-Souza, C., Cruz-López, M. I., & Rivera-Monroy, V. H. (2022). Development and Structural Organization of Mexico's Mangrove Monitoring System (SMMM) as a Foundation for Conservation and Restoration Initiatives: A Hierarchical Approach. Forests, 13(4). https://doi.org/10.3390/f13040621

Roslinda, E., Listiyawati, L., Ayyub, A., & Fikri, F. Al. (2021). The Involvement of Local Community in Mangrove Forest Conservation in West Kalimantan. Jurnal Sylva Lestari, 9(2). https://doi.org/10.23960/jsl29291-301

Roy, A. K. D. (2016). Local community attitudes towards mangrove forest conservation: Lessons from Bangladesh. Marine Policy, 74. https://doi.org/10.1016/j.marpol.2016.09.021

Rumondang, R., Feliatra, F., Warningsih, T., & Yoswati, D. (2024). Sustainable management model and ecosystem services of mangroves based on socio-ecological system on the coast of Batu Bara Regency, Indonesia. Environmental Research Communications, 6(3). https://doi.org/10.1088/2515-7620/ad2d01

Saoum, M. R., & Sarkar, S. K. (2024). Monitoring mangrove forest change and its impacts on the environment. Ecological Indicators, 159, 111666. https://doi.org/10.1016/j.ecolind.2024.111666

Sofian, A., Kusmana, C., Fauzi, A., & Rusdiana, O. (2019). Ecosystem services-based mangrove management strategies in Indonesia: A review. AACL Bioflux, 12(1).

Song, W., Hou, Y., Zhu, W., Fan, Y., Xu, H., Cai, C., Li, G., & Huang, L. (2024). Enhancement effects of mangrove restoration on blue carbon storage in Qinzhou Bay. Frontiers in Forests and Global Change, 7. https://doi.org/10.3389/ffgc.2024.1328783

Su, J., Friess, D. A., & Gasparatos, A. (2021). A meta-analysis of the ecological and economic outcomes of mangrove restoration. Nature Communications, 12(1). https://doi.org/10.1038/s41467-021-25349-1

Susilo, N. B., Koestoer, R. H., & Takarina, N. D. (2023). Disclosure of mangrove conservation policies in SEA: Bibliometric content perspectives. Journal of Marine and Island Cultures, 12(2). https://doi.org/10.21463/jmic.2023.12.2.08

Veettil, B. K., Ward, R. D., Quang, N. X., Trang, N. T. T., & Giang, T. H. (2019). Mangroves of Vietnam: Historical development, current state of research and future threats. In Estuarine, Coastal and Shelf Science (Vol. 218). https://doi.org/10.1016/j.ecss.2018.12.021

Wang, Y. S., & Gu, J. D. (2021). Ecological responses, adaptation and mechanisms of mangrove wetland ecosystem to global climate change and anthropogenic activities. In International Biodeterioration and Biodegradation (Vol. 162). https://doi.org/10.1016/j.ibiod.2021.105248

Zaldívar-Jiménez, A., Ladrón de Guevara-Porras, P., Pérez-Ceballos, R., Díaz-Mondragón, S., & Rosado-Solórzano, R. (2017). US-Mexico joint gulf of Mexico large marine ecosystem based assessment and management: Experience in community involvement and mangrove wetland restoration in Términos lagoon, Mexico. In Environmental Development (Vol. 22). https://doi.org/10.1016/j.envdev.2017.02.007