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Human Ecology and Adaptive Governance in Vulnerable Mangrove Ecosystems: Global Trends and Implications for Indonesia

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ABSTRAK

Mangrove ecosystems are vital for coastal socio-ecological resilience, yet governance outcomes often remain weak due to institutional fragmentation and escalating climate risks. This study combines a PRISMA 2020 systematic review with bibliometric mapping (VOSviewer) of 520 Scopus-indexed publications (2000–2025) to trace global research evolution and derive Indonesia-relevant insights. Publication output accelerated sharply after 2018, peaking at >60 documents in 2024, and research production is concentrated in high-income countries (e.g., the United States ~18.6%), while Indonesia contributes only ~9.7% despite hosting the world's largest mangrove extent. Keyword mapping identifies three dominant clusters—ecological foundations, human ecology and governance, and environmental dynamics—with recent trends shifting toward climate–governance and resilience themes. The key gap is that governance and resilience discourse rarely translates into an integrated institutional design linking multi-level coordination, community adaptive capacity, and long-term financing; the novelty of this study is the Dynamic Adaptive Institutional Alignment Framework that explicitly integrates these components to inform Indonesia-oriented governance reform. Findings support moving beyond restoration targets toward adaptive, learning-based, and financially durable governance architectures. The study contributes theoretically by operationalizing adaptive governance within mangrove socio-ecological systems and offers policy guidance for strengthening climate-responsive and inclusive coastal governance under conditions of increasing uncertainty.

Kata Kunci: human ecology; adaptive governance; mangrove ecosystems; socio-ecological system; vulnerability; climate resilience; sustainable livelihoods; systematic literature review

INTRODUCTION

Mangrove ecosystems are pivotal components of tropical socio-ecological systems, providing coastal protection, supporting biodiversity, and sustaining the livelihoods of millions of people in low-lying coastal regions (Du et al., 2025; Dulyakasem et al., 2026; Zu Ermgassen et al., 2020). Historically, research on mangroves has emphasized their ecological functions, conservation measures, and restoration efforts. This ecological emphasis is reflected in early global scholarship, which predominantly examined mangroves as bio-physical systems and highlighted their role in ecosystem productivity, biodiversity support, and coastal stability (Rodríguez-Rodríguez et al., 2024).

Mangrove forests—distributed across more than 120 countries—comprise around 80 "true mangrove" species with substantial ecological and ethnobiological significance. These intertidal ecosystems offer a wide range of provisioning, regulating, and cultural services, including timber, fuelwood, medicines, fisheries, carbon sequestration, nutrient cycling, and tourism benefits (Sannigrahi et al., 2020). Yet, despite their recognized value, mangroves continue to face degradation driven by aquaculture expansion, agricultural conversion, urbanization, and coastal development, with governance weaknesses often amplifying ecological pressures (Gerona-Daga & Salmo, 2022).

Historically, mangrove research was dominated by ecological and restoration-oriented approaches, focusing on ecosystem functions, biodiversity, and biophysical monitoring (Rodríguez-Rodríguez et al., 2024). Over the past decade, however, scholarship has increasingly moved toward socio-ecological perspectives that recognize inseparable interactions between ecological dynamics and human livelihoods, institutions, and adaptive capacity (Cinner et al., 2018; Du et al., 2025). Bibliometric evidence also indicates a broader transition from ecology-centered studies to governance-, adaptation-, and resilience-oriented research, particularly after 2018

(Beddu et al., 2025). This shift suggests that mangrove sustainability is not only an ecological challenge but also an institutional challenge requiring cross-scale coordination, participation, and learning-based governance (Chaffin et al., 2014; Folke et al., 2005).

Despite these global developments, governance constraints remain particularly pronounced in Indonesia, which hosts the world's largest mangrove extent. However, mangrove governance is characterized by persistent institutional fragmentation, overlapping mandates among ministries and subnational authorities, weak policy coherence, and limited cross-sectoral coordination, which collectively undermine conservation and restoration effectiveness and constrain the adaptive capacity of mangrove-dependent communities (Dharmawan et al., 2016; Mursyid et al., 2021). These governance challenges highlight the need for an adaptive governance framework capable of integrating ecological restoration, livelihood resilience, and institutional coordination.

Although governance and resilience themes are increasingly visible in mangrove scholarship, the literature rarely operationalizes an integrated institutional design that simultaneously links multi-level coordination, community adaptive capacity, and long-term financing mechanisms within a unified socio-ecological governance framework—especially for fragmented multi-ministerial settings such as Indonesia (Beddu et al., 2025; Mursyid et al., 2021). To address this gap, this study advances a Dynamic Adaptive Institutional Alignment Framework that integrates human ecology (livelihood dependence, social dynamics, local institutions) with adaptive governance (flexibility, social learning, cross-level coordination) to provide an operational pathway for resilient mangrove governance under climate uncertainty (Chaffin et al., 2014; Folke et al., 2005).

This study contributes in three ways. Methodologically, it applies a PRISMA 2020 systematic review and bibliometric mapping (VOSviewer) of Scopus-indexed publications (2000–2026) to trace research evolution and identify thematic transitions in mangrove governance scholarship (Page et al., 2021). Theoretically, it consolidates human ecology and adaptive governance into a structured analytical framework that bridges ecological processes, livelihood systems, and institutional design. Practically, it translates the synthesis into policy-relevant directions for Indonesia by emphasizing institutional harmonization, community-based adaptive capacity, and long-term financing continuity as pillars for climate-responsive mangrove governance. Through this integration, the study aims to clarify the evolution of mangrove scholarship, identify persistent governance challenges in Indonesia, and propose a conceptual pathway to strengthen climate-resilient, socio-ecological governance in mangrove-dependent regions. The findings are expected to contribute to blue economy strategies, institutional reform discussions, and adaptive coastal policy design.

Overall, this paper argues that resilient mangrove management requires moving beyond restoration targets toward adaptive institutional alignment—a governance architecture that coordinates mandates across sectors and scales, strengthens community adaptive capacity, and secures long-term financing for sustained learning and implementation. By integrating global evidence with Indonesia's governance realities, the study offers a theory-informed and policy-relevant framework to support more coherent, inclusive, and climate-responsive mangrove governance.

RESEARCH METHODS

This study employed a Systematic Literature Review (SLR) following PRISMA 2020 (Moher et al., 2015; Page et al., 2021), and bibliometric mapping to examine research trajectories on mangrove governance within a human ecology and adaptive governance lens. To ensure temporal consistency and avoid incomplete-year bias, the review period was defined as 2000–2025. The Scopus search was executed using a year filter equivalent to PUBYEAR > 1999 AND PUBYEAR < 2026, ensuring that the dataset represents complete publication years up to 2025.

Scopus was selected due to its broad coverage of peer-reviewed journals and consistent metadata for bibliometric analysis. The search was conducted on 9/11/2025 using Scopus advanced search. The search string was: (TITLE-ABS-KEY(mangrove) AND TITLE-ABS-KEY(human) AND TITLE-ABS-KEY(adaptive) AND TITLE-ABS-KEY(management)) AND PUBYEAR > 1999 AND PUBYEAR < 2026 AND (LIMIT-TO(DOCTYPE, "ar") OR LIMIT-TO(DOCTYPE, "re") OR LIMIT-TO(DOCTYPE, "cp")) AND LIMIT-TO(LANGUAGE, "English"). Document types included research articles (ar), review papers (re), and conference papers (cp). Only English-language publications were retained to ensure comparability of keyword mapping and interpretability of governance terminology. **Rationale for keyword selection**. The query was designed to capture (i) the ecological domain (mangrove), (ii) the human

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dimension (human), (iii) adaptive governance/ adaptation orientation (adaptive), and (iv) the management/governance domain (management). This combination was intended to balance recall and precision, avoiding a purely ecological corpus while still retaining governance-related studies relevant to socio-ecological systems.

Studies were included if they met all the following criteria:

1. Focused on mangrove ecosystems;
2. Addressed at least one governance-relevant dimension (e.g., institutions, policy, participation, co-management, adaptive capacity, resilience, vulnerability, stakeholder coordination);
3. Contained empirical findings, conceptual frameworks, or systematic syntheses relevant to socio-ecological governance;
4. Peer-reviewed and indexed in Scopus;
5. Published within 2000–2025;
6. English language; DOCTYPE ar/re/cp.

Studies were excluded if:

1. They were purely biophysical/ecological with no governance or human-dimension relevance (e.g., species-only physiology without management implications);
2. They focused on non-mangrove coastal ecosystems without explicit mangrove relevance;
3. They were editorials, notes, short communications, book chapters, theses/ dissertations, or grey literature (not covered by the selected DOCTYPE filters);
4. They lacked sufficient metadata (e.g., missing title/abstract/keywords) for screening and bibliometric processing.

Screening followed the PRISMA 2020 workflow: identification, screening, eligibility, and inclusion (see Figure 1). Identification: The initial search returned n = 820 records. Deduplication: A duplicate check was conducted during data import; no duplicated entries were detected in the exported Scopus dataset (duplicates removed: n = 0), therefore n = 820 proceeded to screening. Title–abstract screening: Titles and abstracts were screened using the inclusion/ exclusion criteria. n = 172 records were excluded at this stage, primarily because they were purely ecological/biophysical without governance linkage or were not relevant to mangrove governance. This resulted in n = 648 records for full-text assessment. Full-text eligibility assessment: Full texts were assessed to confirm conceptual fit with human ecology/adaptive governance relevance. n = 128 records were excluded for reasons such as: (i) governance not substantively addressed (only mentioned superficially), (ii) ecological focus without institutional implications, or (iii) insufficient linkage to socio-ecological governance. Final inclusion: The final dataset consisted of n = 520 publications included for qualitative synthesis and bibliometric mapping.

Bibliometric data validation and cleaning were conducted to ensure metadata consistency and reduce noise prior to co-occurrence mapping. The procedures included:

1. Metadata completeness checks (missing year, keywords, source title);

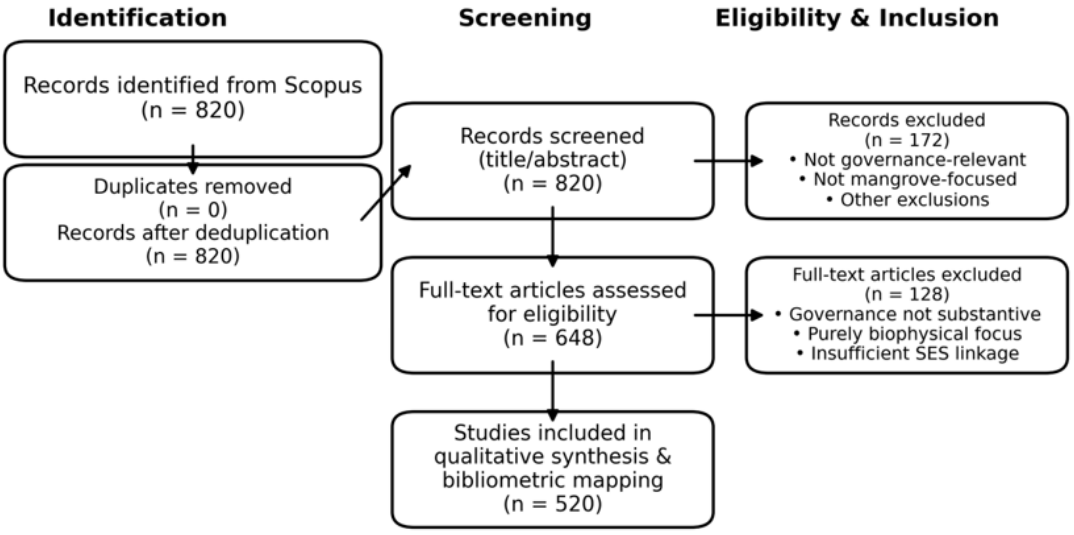

Figure 1. PRISMA 2020 flow diagram of study selection (2000–2025).
Source: Author's screening process based on Scopus search results, 2025.

2. Keyword normalization (singular/plural, hyphenation, capitalization; e.g., "co-management" vs "comanagement," "climate-change" vs "climate change");
3. Synonym harmonization for high-frequency terms (e.g., "mangroves" merged into "mangrove");
4. Noise removal (non-informative terms and generic words);
5. Outlier screening for records with unrelated keyword sets due to indexing inconsistencies, followed by re-checking against inclusion criteria.

These procedures ensured that co-occurrence patterns represent conceptual structures rather than metadata artefacts.

Keyword co-occurrence analysis employed fractional counting to reduce bias associated with publications containing multiple keywords, thereby improving comparability across documents. A minimum occurrence threshold of 5 was applied to include keywords with sufficient frequency for stable mapping. From an initial pool of 520 keywords, 175 met the threshold and were retained for network visualization (Figures 3–4). Network, overlay (average publication year), and density visualizations were generated using VOSviewer default layout settings to maintain interpretability and reproducibility. Co-occurrence mapping used fractional counting was applied to reduce bias from multi-keyword papers with network, overlay (average publication year), and density visualizations generated. Cluster resolution and layout settings were kept at default to maintain interpretability and reproducibility.

Interpretation was guided by an integrated framework combining human ecology and adaptive governance. Human ecology was used to interpret livelihood dependence, vulnerability, and community dynamics, while adaptive governance was used to interpret institutional flexibility, cross-level coordination, social learning, and multi-actor collaboration. The global corpus was analyzed as a single evidence base, while Indonesia was examined as a focused contextual layer in the Results and Discussion section for policy-relevant interpretation.

RESULTS AND DISCUSSION

Global Research Transformation: From Ecology to Governance Paradigm

Global mangrove research has undergone a marked conceptual evolution over the past three decades, transitioning from a predominant focus on ecological functions and conservation biology toward integrated analyses that consider human dimensions, institutional governance, and socio-ecological resilience. Early foundational work characterized mangroves primarily through their ecological services—biodiversity support, carbon sequestration, shoreline protection—and identified stark patterns of global loss due to anthropogenic pressure (Friess et al., 2019). This influential synthesis emphasized both mangroves' critical ecosystem functions and the limits of conservation strategies that neglect human drivers.

Throughout the 1990s and early 2000s, literature sustained this ecological orientation, with ecological monitoring and restoration strategies dominating scholarly output. However, recent large-

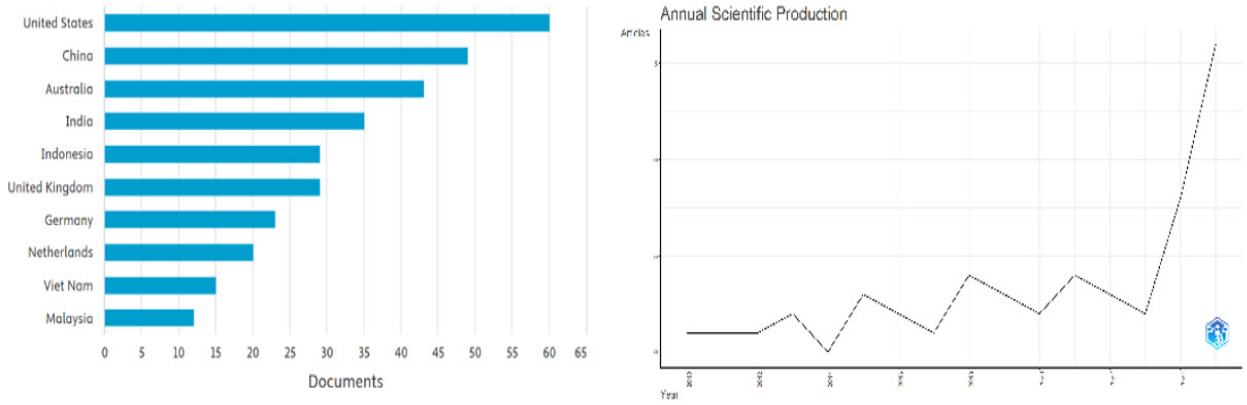

Figure 2. Geographical Distribution and Annual Publication Trends In Mangrove Adaptive Governance Research (2000–2025)

Source: Author's analysis based on Scopus database (2000–2025).

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scale reviews highlight that decision frameworks and analytical tools increasingly incorporate socio-economic and governance variables alongside ecological metrics, signaling a substantive conceptual shift in research emphases (Rodríguez-Rodríguez et al., 2024). Such studies document a rising trend in bibliometric indicators tied to human dimensions—such as vulnerability, community perceptions, and governance outcomes—suggesting that research is no longer confined to biophysical assessment alone. The geographical distribution of publications and the acceleration of annual outputs further illustrate this structural shift in global mangrove scholarship (Figure 2).

As shown in Figure 2, publication output increased sharply after 2018, coinciding with the global mainstreaming of climate adaptation and blue carbon policy frameworks. Moreover, research production remains concentrated in high-income countries, while tropical countries with the largest mangrove coverage—including Indonesia—remain underrepresented. This imbalance suggests a structural asymmetry in knowledge production and highlights the importance of contextualizing adaptive governance discourse within national institutional settings. This transformation aligns with broader developments in socio-ecological systems (SES) theory, which contend that human behaviour, institutional processes, and ecological dynamics are deeply intertwined and cannot be examined in isolation. SES frameworks trace their intellectual roots to work on coupled human–environment systems and adaptive co-management, arguing that ecological sustainability is contingent on governance systems capable of responding to uncertainty, stakeholder heterogeneity, and cross-scale interactions (Mahardika et al., 2023).

The overlay visualization (Figure 4) confirms a temporal shift from ecological monitoring and restoration toward governance, resilience, and adaptation themes in more recent publications. However, the rise of climate–resilience discourse is not consistently matched by operational institutional design elements, such as multi-level coordination mechanisms, financing continuity, and institutional alignment. This finding reinforces the institutional integration gap identified in the bibliometric analysis.

In addition to the thematic evolution observed in the bibliometric mapping, a closer examination of the reviewed corpus reveals an uneven distribution of analytical focus. Approximately two-thirds of the publications remain predominantly ecology-oriented, emphasizing restoration techniques, biodiversity metrics, and carbon dynamics. Around one-third incorporate governance or socio-economic

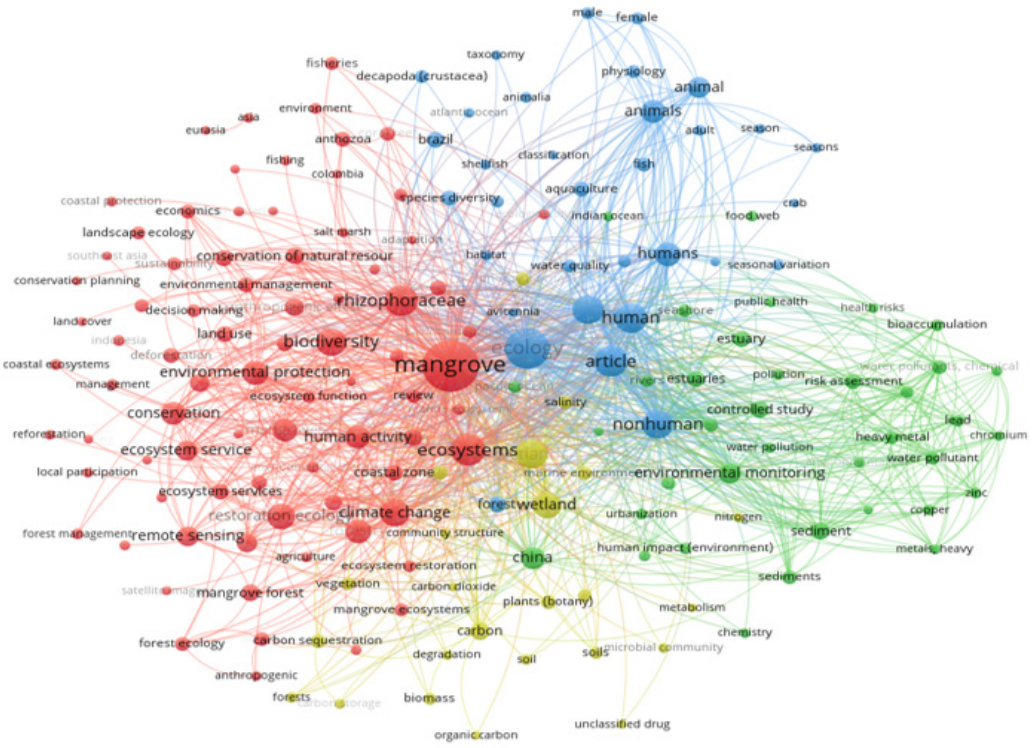

Figure 3. Visualization of Keyword Co-Occurrence Linkages In Mangrove Adaptive Governance Research.
Source: Author's bibliometric analysis using VOSviewer based on Scopus database (2000–2025).

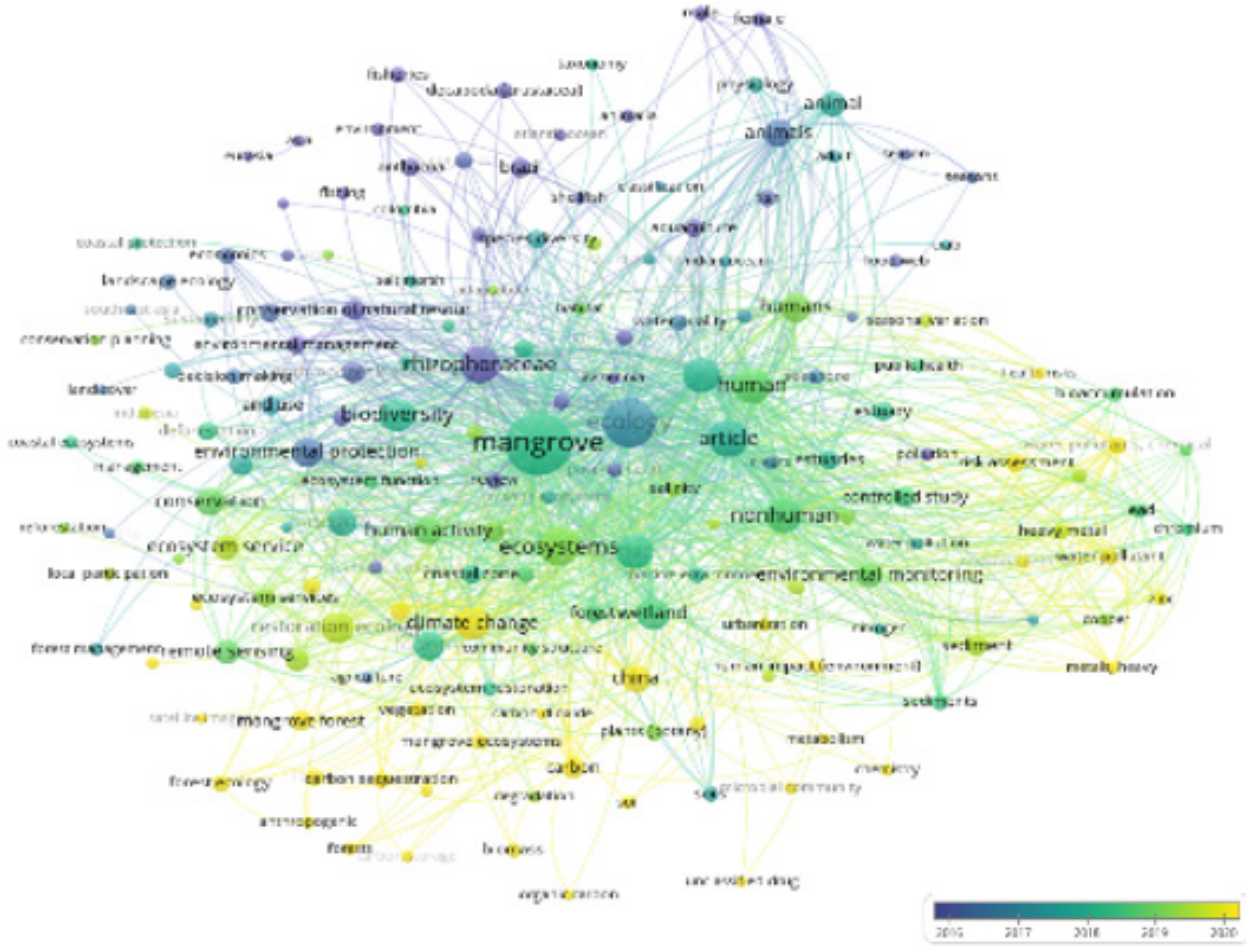

Figure 4. Temporal Overlay Visualization of Keyword Occurrence in Mangrove Adaptive Governance Research.
Source: Author's bibliometric analysis using VOSviewer based on Scopus database (2000–2025).

dimensions, yet only a smaller proportion explicitly operationalize adaptive governance frameworks or multi-level institutional analysis. Moreover, the majority of studies rely on qualitative case-study approaches, with limited longitudinal institutional assessments or comparative quantitative governance evaluations. This distribution confirms that while governance discourse is expanding, systematic institutional integration and performance-based evaluation remain underdeveloped within mangrove scholarship.

Taken together, the keyword network and overlay analyses indicate that, despite the growth of governance and resilience themes, the literature rarely operationalizes an integrated institutional design that links multi-level coordination, community adaptive capacity, and long-term financing continuity within a single socio-ecological governance framework—especially in fragmented multi-ministerial contexts such as Indonesia.

Concurrently, emerging research explicitly interrogates governance structures, stakeholder pluralism, and institutional performance in mangrove contexts. For instance, Poti et al., (2025) demonstrates the limitations of top-down governance and the failure of restoration initiatives that do not integrate local knowledge or multi-actor collaboration. Moreover, recent political ecology work emphasizes the political significance of local voices and governance legitimacy in shaping both research agendas and policy practice. This line of inquiry underscores that mangrove sustainability is not solely an ecological or technical challenge, but inherently a governance one involving power dynamics, legitimacy, and contestation over resource use (Chávez-Páez et al., 2025; Chávez-Páez & Beitl, 2025).

A synthesis of these literatures shows clear evidence of an expanding research frontier: whereas early studies concentrated on ecological descriptions and management prescriptions, contemporary work increasingly engages with governance, socio-economic determinants, and

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resilience thinking. This shift reflects the emerging consensus that effective mangrove conservation and sustainable use demand integrated approaches that reconcile ecological imperatives with institutional capacities, stakeholder engagement, and adaptive policy frameworks. To further illustrate how adaptive governance has been conceptualized and operationalized in recent mangrove scholarship, a structured synthesis of key peer-reviewed studies is presented in Table 1.

As shown in Table 1, recent studies converge on three dominant governance dimensions: institutional flexibility, multi-actor collaboration, and cross-scale coordination. However, only a limited number of studies explicitly integrate these governance attributes with human ecology variables such as livelihood dependence, vulnerability, and local knowledge systems. This conceptual fragmentation reinforces the need for a more integrative analytical framework.

The structural fragmentation identified in the bibliometric network and temporal evolution analysis suggests that mangrove scholarship is currently situated in a transitional epistemic phase. While governance, resilience, and climate adaptation have gained prominence, the literature has yet to consolidate these themes within a coherent institutional design framework that systematically integrates ecological processes, community dynamics, and cross-scale governance mechanisms. This conceptual dispersion indicates that the challenge is not the absence of governance discourse, but the absence of integrative alignment between human ecology and adaptive institutional architecture.

To address this gap, the following section advances a theoretical synthesis that explicitly bridges human ecology perspectives—grounded in livelihood systems and socio-cultural dynamics—with adaptive governance theory—focused on institutional flexibility, cross-level coordination, and learning-based policy adjustment. By integrating these traditions, the study seeks to move beyond descriptive governance narratives toward an operational framework capable of guiding resilient mangrove governance in complex coastal systems.

Table 1. Synopsis of Recent Articles on Mangrove Adaptive Governance.

Article Topics	Method	Highlight (Key Insights)	Reference
Adaptive Governance in Social–Ecological Systems	Literature review and coastal governance case studies	Adaptive governance enhances ecosystem resilience through social learning, collaboration, flexible decision-making, and iterative policy adjustment	(Chaffin et al., 2014; Folke et al., 2005)
Adaptive Capacity in Coastal Communities	Quantitative cross-country surveys	Education, livelihood diversification, access to information, and social networks strengthen adaptive capacity to climate impacts	(Cinner et al., 2018)
Environmental Governance & Stakeholder Collaboration	Mixed methods: surveys + interviews	Success of mangrove governance depends on stakeholder participation, institutional legitimacy, and coordinated multi-level governance; fragmentation weakens outcomes	(Mursyid et al., 2021; Thompson & Harris, 2021)
SES Vulnerability & Adaptive Capacity Measurement	Quantitative SES vulnerability index (SESVI) using biophysical & social indicators	SESVI captures spatial variations in socio-ecological vulnerability and is effective for adaptive governance decision-support	(De Vos et al., 2025; Espinoza Córdova et al., 2024)
Community-Based Mangrove Management in Indonesia	Participatory case studies	Many conservation failures arise from weak coordination, limited research, and lack of local legitimacy; community institutions are central for adaptive co-management	(Damastuti & De Groot, 2017)

Theoretical Integration: Human Ecology and Adaptive Governance

The governance of mangrove ecosystems cannot be fully understood through ecological or institutional lenses in isolation; rather, it requires a socio-ecological integration that synthesizes human ecology with adaptive governance mechanisms. Human ecology, as a theoretical orientation, frames mangrove landscapes as coupled systems where human livelihoods, economic incentives, cultural practices, and ecosystem functions are co-constitutive. Research grounded in socio-ecological systems (SES) theory emphasizes that ecological sustainability and human well-being are mutually dependent, with governance failures often rooted in misalignments between human behaviour and environmental dynamics. The SES approach underscores that effective management requires understanding how social drivers—livelihood strategies, perceptions of resource risk, and community norms—interact with ecological processes to shape outcomes in complex, dynamic environments (Du et al., 2025).

Classical SES frameworks, developed to analyse coupled human–environment interactions, highlight the importance of feedbacks, cross-scale dynamics, and adaptive capacity. Elinor Ostrom's general framework for sustainability of social-ecological systems emphasizes that outcomes are driven by interactions among resource systems, governance systems, and actors, and that institutions are central in mediating these interactions (Mahardika et al., 2023). Empirical applications of SES analysis in mangrove contexts show that sustainable governance depends not only on ecological conditions but on the fit between institutional arrangements and community needs, social capital, and the capacity to negotiate conflict and build consensus across stakeholders.

Building on SES insights, adaptive governance theory provides a normative and analytical scaffold for understanding how governance systems can respond to complexity and change. Adaptive governance is characterized by four core attributes: institutional flexibility, multi-level coordination, social learning, and stakeholder collaboration. It acknowledges that governance structures must be capable of learning from ecological outcomes, experimenting with policy alternatives, and adjusting strategies in response to feedback from both social and biophysical systems (Folke et al., 2005). This perspective is supported by interdisciplinary governance research that situates mangrove ecosystems as inherently dynamic and multi-scalar, requiring governance arrangements that transcend rigid, top-down regulatory models (Nasution et al., 2025).

Adaptive governance also draws on literature in collaborative environmental governance, which emphasizes the necessity of bridging institutions and stakeholders across spatial and jurisdictional scales to address mismatches between ecosystem structures and governance boundaries. In mangrove SESs, collaborative governance implies engaging local communities, government agencies, NGOs, and private sectors in participatory decision-making platforms that legitimize diverse knowledge systems and co-produce management strategies. Such collaboration enhances social capital and trust, which are widely recognized as social reservoirs of resilience under uncertainty.

Importantly, empirical research on mangrove governance illustrates the consequences of governance exclusion and rigid authority structures. Poti et al., (2025) demonstrate how top-down management without local integration undermines ecological outcomes and fails to leverage community knowledge in mangrove restoration, highlighting a practical limitation of non-adaptive governance approaches in SES contexts. Complementary evidence from socio-ecological studies reveals that community perceptions, institutional legitimacy, and local economic dependencies significantly influence the success of co-management systems, reinforcing the centrality of integrating human ecology within governance frameworks (Cruz Portorreal et al., 2024).

Taken together, the theoretical integration of human ecology and adaptive governance offers a rigorous lens to analyse mangrove socio-ecological systems. Human ecology grounds governance analysis in the lived realities of coastal communities, elucidating how economic pressures, cultural practices, and perceptions shape resource use patterns. Adaptive governance, in turn, provides a mechanism for institutional responsiveness, enabling governance systems to navigate uncertainty, integrate multi-actor knowledge, and evolve in tandem with ecological change. This integration is crucial for transforming mangrove governance from static regulatory regimes to dynamic systems capable of steering resilient socio-ecological futures.

The review also exposes methodological concentration and epistemic limitations within existing scholarship. Many governance-oriented studies remain context-specific and short-term, limiting cross-case comparability and policy transferability. Institutional performance is

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frequently discussed normatively rather than measured empirically, and financing mechanisms—particularly long-term fiscal integration—are rarely incorporated into governance analysis. This methodological imbalance constrains the development of cumulative institutional learning across mangrove contexts and underscores the need for structured governance frameworks that can bridge descriptive case evidence with systemic institutional design.

Indonesia's Structural Governance Gap

Indonesia hosts the world's largest mangrove extent, yet governance responsibilities remain distributed across multiple ministries and subnational authorities, often producing overlapping mandates, policy incoherence, and weak cross-sector coordination. Evidence from Indonesian governance studies highlights recurring constraints: ambiguous jurisdiction across forest and non-forest zones, inconsistent enforcement, misalignment between spatial planning instruments, and limited institutionalized mechanisms for sustained stakeholder collaboration. These structural conditions are not merely administrative issues; they directly shape livelihood security, access rights, and adaptive capacity in mangrove-dependent communities, thereby reducing the effectiveness and durability of restoration outcomes.

While the systematic review was conducted on a global dataset without geographic separation, Indonesia was examined as a contextual case within the broader analytical synthesis. This approach allows the study to situate Indonesia's governance dynamics within global research patterns while identifying context-specific institutional challenges. Indonesia hosts the largest mangrove extent globally, accounting for roughly one-fifth of the world's total mangrove coverage. Despite significant restoration commitments under national climate and FOLU Net Sink strategies, governance responsibilities remain distributed across multiple ministries and subnational authorities, often resulting in mandate overlap and coordination inefficiencies. While restoration targets have expanded in scale, institutional alignment across forestry, marine, spatial planning, and regional development sectors remains incomplete. This structural fragmentation limits policy coherence and weakens the long-term adaptive capacity of mangrove-dependent communities.

Despite being home to the world's largest mangrove expanse, Indonesia faces persistent structural governance challenges that impede effective mangrove management. National policy frameworks exist, including Law No. 27/2007 (revised by Law No. 1/2014) on coastal areas and small islands, as well as Presidential Decrees relating to mangrove management strategies. However, implementation on the ground remains constrained by overlapping institutional mandates and regulatory fragmentation. Multiple sectoral authorities—particularly the Ministry of Environment and Forestry (MoEF) and the Ministry of Marine Affairs and Fisheries (MMAF)—exercise jurisdiction over mangrove resources depending on administrative categorization, creating ambiguity in legal responsibility and operational coordination. This structural misalignment between land-based and sea-based governance regimes generates significant policy incoherence and implementation gaps at the local level (Arifanti et al., 2022).

A comprehensive review of Indonesian mangrove governance finds that these contradictory authorities and unclear boundaries between regulatory regimes hinder both compliance and stakeholder engagement. For example, mangrove areas categorized as state forests fall under MoEF stewardship, whereas areas outside forest zones, including intertidal spaces, are regulated by MMAF and integrated into spatial planning decisions. The separation of regulatory objectives across these agencies often leads to inconsistent enforcement, contradictory land-use decisions, and weak policy coherence that undermine conservation efforts (Arifanti et al., 2022).

Institutional fragmentation also weakens the operationalization of collaborative conservation strategies such as co-management and community participation, which are recognized in global governance literature as critical for resilient socio-ecological systems. Empirical evidence from Indonesia shows that while local communities possess valuable ecological knowledge and have a strong stake in resource outcomes, their formal inclusion in decision-making processes remains limited due to weak institutional linkages and inadequate recognition of community governance roles (Tjitjik Rahaju et al., 2025).

Furthermore, policy analyses indicate that limited coherence across planning instruments—such as between Regional Spatial Plans (*Rencana Tata Ruang Wilayah/RTRW*) and Coastal Zone & Small Island Zoning Plans (*Rencana Zonasi Wilayah Pesisir dan Pulau-Pulau Kecil/RZWP3K*)—exacerbates uncertainty for local managers and investors, leading to inconsistent mangrove protection and conflicting land-use outcomes. This lack of integration is

symptomatic of a broader governance pattern in which sectoral regulations and planning frameworks are not sufficiently harmonized to address the socio-ecological complexity of mangrove systems.

These structural gaps are not merely administrative inefficiencies; they translate directly into socio-economic consequences for coastal communities. Without cohesive governance frameworks, livelihood sustainability, equitable access to ecosystem services, and community adaptive capacity are compromised. Policy fragmentation dilutes responsibility among agencies, making it difficult to enforce environmental protections, deliver incentives for sustainable practices, and establish clear accountability for environmental outcomes. As a result, mangrove degradation persists even in areas under formal protection, and community engagement in adaptive management remains underdeveloped (Mursyid et al., 2021).

In response to these challenges, recent studies emphasize the need for integrated governance mechanisms that bridge multi-level and multi-actor coordination, such as collaborative governance and adaptive co-management frameworks that involve state agencies, local governments, and community stakeholders. Such approaches are shown to improve policy alignment and empowerment of local actors, enhancing governance legitimacy and long-term sustainability of mangrove ecosystems (Sawir & Sumardi, 2025).

Policy Implications for Indonesia: Toward Adaptive Institutional Alignment

The findings of this study indicate that Indonesia's mangrove governance challenge is not primarily a technical problem of restoration scale, but a structural issue of institutional alignment. While national restoration targets and carbon-based commitments (e.g., FOLU Net Sink 2030) signal strong political will, empirical governance literature consistently shows that ecological targets alone are insufficient without institutional coherence and adaptive capacity (Chaffin et al., 2014; Folke et al., 2005). Therefore, advancing mangrove sustainability requires a shift from output-oriented restoration metrics toward systemic institutional reform grounded in adaptive governance principles. Three strategic pathways are proposed.

1. Multi-Level Institutional Harmonization

Indonesia's mangrove governance operates within a multi-layered regulatory architecture involving the Ministry of Environment and Forestry (MoEF), the Ministry of Marine Affairs and Fisheries (MMAF), spatial planning authorities, and subnational governments. Comparative governance research demonstrates that fragmentation across administrative scales often leads to policy incoherence, reduced accountability, and weakened environmental outcomes (Cumming et al., 2022). In coastal systems, mismatches between ecological boundaries and jurisdictional boundaries are widely recognized as a core governance failure (Cash et al., 2006).

In the Indonesian context, overlapping mandates between forest-based and marine-based regulatory regimes produce ambiguity in enforcement and spatial designation (Mursyid et al., 2021; Arifanti et al., 2022, Forests). Such fragmentation undermines restoration effectiveness and complicates the operationalization of *Kawasan Ekosistem Esensial* (KEE), which requires cross-sectoral coordination but remains weakly integrated into spatial planning instruments.

Embedding adaptive governance principles within national frameworks—particularly FOLU Net Sink 2030 and blue economy strategies—can enhance institutional coherence by: integrating mangrove carbon accounting into regional development planning, harmonizing spatial planning instruments (RTRW and RZWP3K), and establishing cross-ministerial coordination platforms. Empirical evidence from multi-level environmental governance studies shows that institutional harmonization improves resilience when coordination mechanisms are formalized and supported by shared data systems and monitoring platforms (Ostrom, 2009; Young, 2017). Thus, mangrove governance reform must prioritize structural alignment rather than sectoral expansion.

2. Strengthening Community-Based Adaptive Capacity

Human ecology research demonstrates that socio-ecological resilience is deeply conditioned by local institutional capacity, livelihood diversification, and social capital (Adger, 2006; Cinner et al., 2018). In mangrove-dependent communities, ecological sustainability and livelihood security are inseparable; degradation directly translates into income instability, food insecurity, and social vulnerability.

Evidence from adaptive co-management literature indicates that governance systems are more robust when community actors are formally recognized as co-producers of environmental

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management (Armitage et al., 2008; Berkes, 2018). Participatory monitoring, co-management arrangements, and benefit-sharing mechanisms enhance institutional legitimacy and improve compliance outcomes in coastal ecosystems (marine policy; ecology and society).

In Indonesia, silvo-fishery systems, eco-tourism initiatives, and sustainable aquaculture practices have demonstrated potential to align conservation with economic incentives. However, without formal institutional recognition and secure tenure arrangements, such initiatives remain vulnerable to policy shifts and regulatory uncertainty (Damastuti & De Groot, 2017; Thompson & Harris, 2021). Therefore, adaptive governance must integrate: livelihood diversification mechanisms (silvo-fishery, eco-tourism, blue carbon incentives), institutionalized participatory monitoring systems, legal recognition of community-based management units, and clear benefit-sharing arrangements.

Research consistently shows that resilience emerges when top-down policy flexibility is combined with bottom-up institutional empowerment (Blythe et al., 2017; Folke et al., 2005). In this sense, adaptive governance is not decentralization per se, but coordinated polycentric governance that enables learning across scales (Hinkel et al., 2014; Vogt et al., 2015; Wang et al., 2023).

3. Long-Term Financing and Policy Continuity

Short-term, project-based restoration programs—often driven by donor cycles or political agendas—frequently undermine institutional learning, weaken accountability, and disrupt long-term ecological monitoring. Governance literature consistently demonstrates that adaptive management requires temporal continuity, iterative feedback mechanisms, and stable institutional memory (Chaffin et al., 2014; Folke et al., 2005; Wang et al., 2023). When restoration initiatives are fragmented into short funding windows, monitoring systems collapse after project closure, cross-sector coordination deteriorates, and community trust erodes. Such discontinuities limit the capacity of governance systems to adjust policies in response to ecological feedback and socio-economic change.

In the context of mangrove ecosystems, long-term sustainability is inseparable from financial durability and institutional commitment. Empirical studies on environmental governance emphasize that resilient socio-ecological systems depend on diversified financing sources, predictable budget allocations, and institutionalized revenue streams that extend beyond annual fiscal cycles (Rakotomahazo et al., 2023). Without sustained financing, restoration efforts risk becoming symbolic interventions rather than embedded governance reforms.

For Indonesia, integrating blue carbon accounting frameworks into national and regional policy instruments offers a strategic pathway to enhance financial continuity. Mangrove ecosystems represent one of the most carbon-dense coastal systems globally, and incorporating their carbon sequestration value into climate mitigation commitments—such as FOLU Net Sink 2030—can unlock performance-based financing mechanisms and carbon market participation (Friess et al., 2019; Sannigrahi et al., 2020). By institutionalizing blue carbon monitoring within national greenhouse gas inventories and regional planning frameworks, mangrove governance can transition from donor-dependent restoration to climate-aligned, revenue-generating environmental management.

Moreover, policy continuity requires embedding mangrove governance within long-term development planning instruments (RPJMN, regional mid-term development plans) rather than treating restoration as a standalone environmental initiative. Institutional economics research indicates that policy durability improves when environmental objectives are integrated into fiscal planning, spatial regulation, and sectoral investment frameworks, thereby reducing vulnerability to political turnover (Berrouet et al., 2018). Stable financing mechanisms may include: performance-based ecological restoration funding linked to carbon outcomes, integration of mangrove conservation into blue economy investment schemes, long-term budget earmarking for ecological monitoring and participatory governance platforms, and blended finance models combining public funds, private investment, and climate finance.

From an adaptive governance perspective, financing is not merely a budgetary issue but a structural enabler of institutional learning. Continuous monitoring, stakeholder engagement, and policy adjustment depend on sustained resource flows. Without financial continuity, adaptive governance remains aspirational rather than operational. Thus, long-term financing and policy continuity form the third pillar of adaptive institutional alignment in Indonesia. Aligning mangrove restoration with blue carbon markets and national climate commitments can transform governance from reactive, project-based interventions into a resilient, learning-oriented system capable of sustaining socio-ecological

resilience across political cycles.

Empirical Anchoring and Practical Implementation of the Adaptive Institutional Alignment Model

Synthesizing the three policy pathways above, this study proposes an Adaptive Institutional Alignment Model for mangrove governance in Indonesia. The model rests on three mutually reinforcing pillars: (1) multi-level institutional harmonization, (2) community-based adaptive capacity strengthening, and (3) long-term financing and policy continuity. Rather than treating these components as independent reforms, the model conceptualizes them as an integrated governance architecture designed to reduce structural fragmentation and enhance socio-ecological resilience.

The first pillar—multi-level institutional harmonization—addresses horizontal and vertical coordination gaps by aligning mandates across forestry, marine, spatial planning, and regional development sectors. This pillar responds directly to scale mismatches and institutional fragmentation identified in global environmental governance literature (Cash et al., 2006; Bodin, 2017). By clarifying jurisdictional boundaries and embedding mangrove governance within national climate and blue economy frameworks, policy coherence becomes structurally embedded rather than administratively negotiated.

The second pillar—community-based adaptive capacity—grounds governance reform in human ecology realities. Mangrove sustainability ultimately depends on the livelihood systems, social capital, and institutional agency of coastal communities. Adaptive co-management and participatory monitoring systems create feedback loops between ecological outcomes and governance decisions, enabling social learning and legitimacy building (Armitage et al., 2009; Folke et al., 2005). This pillar ensures that governance reform does not remain technocratic but becomes socially anchored.

The third pillar—long-term financing and policy continuity—provides temporal stability. Institutional alignment cannot endure without predictable resource flows and embedded policy commitments. Integrating blue carbon accounting into forestry and other land use (FOLU) Net Sink 2030 and blue economy investment schemes transforms mangrove conservation into a climate-finance-linked governance system rather than a short-term restoration project. Financial durability supports monitoring systems, cross-sector coordination, and adaptive experimentation beyond political cycles. These three pillars are integrated within the Adaptive Institutional Alignment Model presented in Figure 5, which synthesizes the study's theoretical and bibliometric insights into an operational framework.

Unlike prior studies that address institutional fragmentation, community-based management, or climate adaptation as separate analytical domains, this study advances an integrated adaptive institutional alignment framework that simultaneously links multi-level coordination, community adaptive capacity, and long-term financing architecture within a dynamic socio-ecological governance system. The novelty lies not merely in synthesizing governance discourse, but

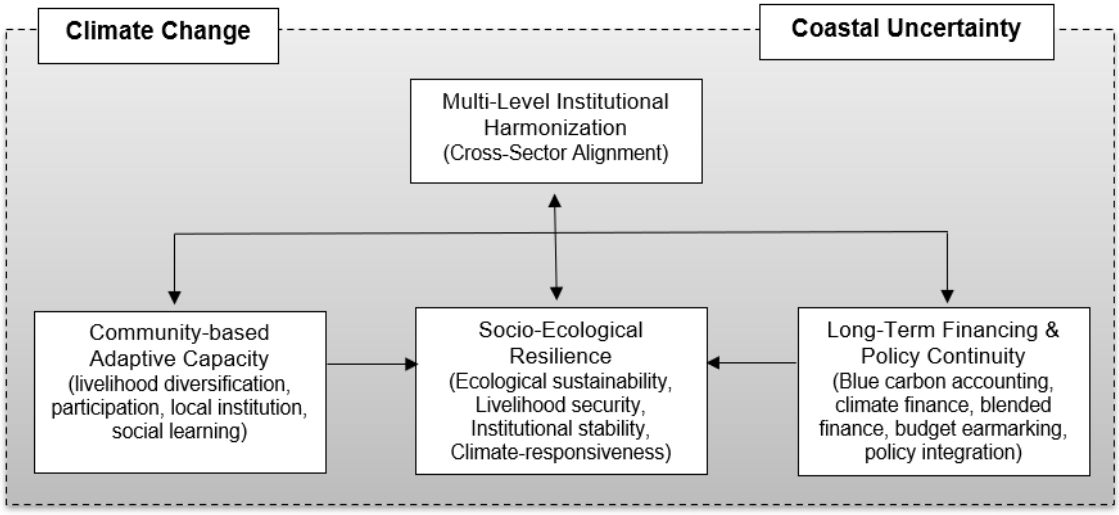

Figure 5. Adaptive Institutional Alignment Model for Mangrove Governance in Indonesia.

Source: Author's conceptual framework developed in this study, 2025.

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in structurally connecting institutional design, livelihood resilience, and fiscal continuity through iterative feedback mechanisms. This integrated architecture moves beyond descriptive governance analysis toward an operationalizable model capable of guiding policy reform in complex coastal systems.

This study has several limitations. First, it relies on Scopus-indexed English-language publications, which may underrepresent Indonesian-language studies and policy-relevant grey literature. Second, bibliometric mapping depends on metadata quality and author keyword practices; despite normalization and cleaning, some thematic signals may be influenced by inconsistent keyword reporting across disciplines. Third, the analysis maps thematic evolution and structural patterns rather than causally evaluating governance effectiveness; therefore, the proposed model should be interpreted as a synthesis framework rather than a tested intervention. Finally, annual publication trends reflect coverage within the selected database and query strategy; alternative databases or search strings may yield different volumes and cluster configurations.

Overall, the evidence indicates that mangrove scholarship is transitioning toward governance and resilience themes, but institutional design integration remains incomplete. For Indonesia, where governance fragmentation persists, durable socio-ecological resilience depends on adaptive institutional alignment that coordinates mandates across sectors, strengthens community adaptive capacity, and secures long-term financing continuity to sustain learning-based implementation under climate uncertainty.

CONCLUSIONS AND POLICY RECOMMENDATION

Conclusions

This study maps research trajectories on human ecology and adaptive governance in mangrove socio-ecological systems using a PRISMA-guided review and bibliometric analysis of Scopus-indexed publications (2000–2025). The bibliometric profile indicates a rapidly growing and highly collaborative field, while keyword patterns show a transition from ecology–restoration dominance toward increasing attention to governance, adaptive capacity, and vulnerability. However, institutional design elements—particularly multi-level coordination mechanisms and financing continuity—remain weakly consolidated across the literature, suggesting a persistent gap between governance discourse and operational governance architecture.

The main contribution of this study is the proposed Adaptive Institutional Alignment Model, which explicitly integrates three implementation-critical pillars—multi-level institutional harmonization, community-based adaptive capacity, and long-term financing continuity—to translate socio-ecological governance concepts into an operational framework for Indonesia. This framework offers a structured pathway for moving beyond restoration targets toward learning-based and institutionally durable mangrove governance under climate and coastal uncertainty.

Policy Recommendation

Strengthening mangrove governance in Indonesia requires an implementation-oriented shift from project-based restoration toward adaptive institutional alignment. At the national level, the priority is to formalize a cross-ministerial coordination mechanism that clarifies roles across forestry, marine affairs, and spatial planning, supported by a single shared spatial baseline and a unified set of indicators. The government should establish a national mangrove governance dashboard that integrates ecological indicators (restoration area, survival rate, carbon proxy), governance indicators (coordination frequency, enforcement actions), and socio-economic indicators (livelihood diversification uptake, participation levels). This is essential to reduce mandate overlap and to ensure accountability across agencies.

At the provincial and district levels, operational implementation should begin through "landscape-based pilot governance units" in priority mangrove areas. These pilots should include: (1) a local co-management forum (government–community–private/NGO) with clear decision rules; (2) participatory monitoring protocols with community reporting schedules; and (3) livelihood packages tied to measurable outcomes (e.g., silvo-fishery standards, eco-tourism governance rules, sustainable aquaculture zoning compliance). Local governments should incorporate mangrove governance targets into mid-term development plans and allocate routine budgets for monitoring and facilitation, not only for planting.

To address financing fragility, Indonesia should institutionalize long-term financing continuity by linking mangrove management to climate finance and blue carbon reporting mechanisms, while ensuring budget earmarking for monitoring and institutional learning. Performance-based funding should be tied to verified ecological and governance milestones (e.g., survival rate

thresholds, monitoring completeness, coordination compliance) to prevent "planting-only" cycles. In practice, the recommended roadmap is: short-term (1–3 years) establish coordination and pilots; medium-term (3–7 years) scale pilots through harmonized spatial planning and standardized monitoring; long-term (>7 years) institutionalize adaptive learning, stable financing, and cross-level governance routines as standard practice rather than project exceptions. Overall, the policy implication is clear: durable mangrove resilience in Indonesia depends less on scaling restoration alone and more on institutional alignment, community adaptive capacity, and financing continuity that enable long-term learning and enforcement.

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AUTHORS CONTRIBUTION STATEMENT

We hereby declare that the contributions of each author to the writing of this paper are: Riesti Triyanti as main contributor, Tri Retnaningsih Soeprobowati, Sri Sumiyati, Nur Arifatul Ulya as member. The authors declare that the Author Contribution Letter has been attached.

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