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# Environmental Ethics, Blue Carbon, and Adaptive Governance in Mangrove Social-Ecological Systems: An Updated Integrative Review of Conservation, Restoration, Monitoring, and Coastal Livelihoods

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## ABSTRACT

Mangrove scholarship has moved beyond descriptive accounts of ecosystem loss toward a more demanding agenda that links ecological diagnosis, restoration design, legal protection, blue-carbon policy, monitoring innovation, and questions of justice. Building on the supplied review corpus and the updated records integrated into the user's files, this article synthesizes how recent literature reframes mangrove systems as ethical social-ecological infrastructures rather than as purely biophysical habitats. The evidence consistently shows that mangroves support biodiversity, fisheries, shoreline stability, carbon storage, and locally embedded livelihoods, yet outcomes remain uneven because restoration, protection, and development decisions are often pursued without adequate attention to tenure, participation, hydrology, monitoring quality, or distributional fairness. Newer studies deepen this picture by showing that legal recognition is widespread but uneven in implementation; that blue-carbon framing can elevate mangroves in national policy while also producing tensions around compensation, restriction, and benefit allocation; and that restoration succeeds only when species choice, geomorphology, salinity, tidal connectivity, and local incentives are matched to place. Methodologically, the field is expanding from classical inventories and stakeholder surveys toward satellite time series, UAV photogrammetry, deep learning, phenocams, and geospatial prioritization, enabling more transparent and adaptive management. This review argues that top-tier mangrove scholarship should move beyond single-objective narratives and instead evaluate success through ecological fit, institutional legitimacy, livelihood justice, and accountable monitoring. It proposes an integrative framework in which environmental ethics is not an external add-on but the normative logic linking conservation, restoration, climate mitigation, and coastal resilience.

***Keywords:*** *mangrove environmental ethics; mangrove governance; blue carbon justice; mangrove restoration; remote sensing for mangroves; community-based coastal management; coastal resilience*

## INTRODUCTION

Mangroves are no longer discussed only as coastal vegetation. Across the supplied

literature, they appear as multifunctional infrastructures that stabilize shorelines, support fisheries, store carbon, buffer hazards, and sustain livelihoods that are culturally and economically embedded in coastal landscapes [1]– [4], [7], [8]. These wider framing matters because mangrove outcomes are not determined solely by ecological conditions. They are shaped by the interaction of law, governance capacity, land-use pressure, restoration design, protected-area performance, monitoring systems, and local rights [5], [6], [9]– [12]. The field has therefore moved from a narrow conservation narrative toward a social-ecological and increasingly ethical conversation.

That shift is especially visible in the newer literature. Studies on national legal frameworks and biodiversity targets show that formal protection has expanded, but implementation remains uneven and important losses continue outside protected areas [5], [6]. Governance studies from India and Sri Lanka show that mangrove management falters when community participation is weak, institutional responsibilities overlap, post-disturbance histories are ignored, or restoration is pursued without social legitimacy [11], [12]. Indonesian and other regional studies add that blue carbon, ecotourism, and restoration programs can create opportunity only when hydrology, tenure, and benefit distribution are addressed explicitly [7], [16]–[23]. In other words, mangroves have become a domain in which ecological science and environmental ethics are inseparable.

This article builds on the supplied review corpus to develop a publication-ready synthesis with three upgrades. First, it sharpens the environmental ethics framing. Rather than treating ethics as a decorative conclusion, the review examines how fairness, recognition, accountability, and intergenerational responsibility are embedded in legal design, restoration choice, protected-area governance, and carbon-centered policy [5]– [7], [11], [12], [16], [18], [39]– [41], [51], [52]. Second, it gives stronger weight to the most recent additions in the corpus, particularly the 2025–2026 studies on legal frameworks, GBF alignment, restoration prioritization, protected-area outcomes, microbial recovery, and geospatial monitoring [5], [6], [11], [29], [31]–[35], [41], [51]. Third, it organizes the discussion around a set of summary tables that make the evidence base explicit and usable for future scholarship.

The central argument is straightforward: mangrove management should no longer be judged by one-dimensional indicators such as planting totals, area gain, tourism income, or aggregate carbon potential. Those metrics matter, but each can mislead when detached from site ecology, livelihood context, and governance quality [3], [4], [7], [20], [27], [31], [33], [38], [40]. A top-quality review must instead ask whether interventions are ecologically fit, institutionally workable, socially legitimate, and ethically defensible. That is the logic of the present synthesis.

## LITERATURE REVIEW

### REVIEW BASIS AND SYNTHESIS LOGIC

The review is grounded in the literature corpus already present in the user's files. No external web references were introduced. The working evidence base comprises review papers, governance analyses, stakeholder studies, restoration case studies, geospatial monitoring contributions, blue-carbon and vulnerability studies, and biodiversity-oriented ecological work published between 2017 and 2026 [1]–[12], [27]–[53]. The methodological heterogeneity of these studies makes a statistical meta-analysis inappropriate. Instead, a structured narrative synthesis is more defensible because the aim is to interpret convergences, tensions, and implications across different kinds of evidence.

Three synthesis principles guide the article. The first is co-constitution: ecological outcomes and social institutions are treated as mutually shaping rather than parallel

domains. This is supported by ecosystem-based management work, policy reviews, governance studies, vulnerability research, and restoration practice literature [8], [9], [11], [12], [15]– [18], [39], [40]. The second principle is recency with continuity. Newer studies are used to update the field where they genuinely alter the state of knowledge—for example, on national legal protection, protected-area outcomes, restoration targeting, and belowground recovery—but foundational earlier studies remain essential where they define enduring management problems and concepts [1], [3], [4], [8]–[10], [27], [36], [37]. The third principle is ethical inference with discipline. The review draws normative conclusions only where the studies report evidence about participation, access, burdens, benefits, vulnerability, or institutional mismatch. Ethics here therefore means fairness in decision processes, recognition of affected communities, transparency in trade-offs, proportionality in restrictions, and accountability in implementation [5]– [7], [11], [12], [16], [18], [39]– [41], [51], [52].

The corpus was then organized into six interlocking themes: changing status and pressures; ethics, governance, and policy coherence; restoration and adaptive management; monitoring and analytical innovation; livelihoods, ecotourism, and blue-carbon economies; and an integrated future agenda. This thematic design mirrors the structure of the literature itself. It also allows the article to do more than summarize results. It enables interpretation of how distinct literatures—legal, ecological, technological, and socio-economic—fit together in real-world mangrove management.

A further reason to use thematic synthesis is that the literature rarely reports the same variables in the same way. National legal analysis [5], [6] cannot be collapsed into the same analytic frame as microbial succession in restored stands [35], UAV-based carbon-loss detection [31], or post-conflict governance barriers [12]. Yet these studies are still comparable in one important sense: each show that successful mangrove futures depend on fit. The review therefore uses fit as an integrating concept—ecological fit between intervention and site, institutional fit between law and implementation, and social fit between management rules and livelihood realities. That concept recurs throughout the discussion and is one of the strongest contributions emerging from the supplied literature.

**Table 1. Governance, ethics, and institutional transitions in mangrove systems**

| Focus area | Geographic scope | Main contribution | Ethical/governance implication | Management lesson | Ref. |
|---|---|---|---|---|---|
| Ecosystem-services review | Indonesia | Links ecosystem services to management strategy | Wellbeing claims require ecological safeguards | Integrate valuation, social analysis, and policy design | [1] |
| National biodiversity review | Indonesia | Synthesizes biodiversity and sustainable-management challenges | Ambition without delivery capacity remains fragile | Translate national goals into local implementation | [2] |
| Legal protection frameworks | Global | Shows explicit legal protection is increasingly common but uneven | Legal existence is not equivalent to fair governance | Match law with implementation, finance, and coordination | [5] |

| | | | | | |
|---|---|---|---|---|---|
| GBF target alignment | Global | Finds loss drivers often persist beyond protected areas | Protection can be misaligned with need | Complement area targets with driver-specific reforms | [6] |
| Post-tsunami governance | India | Maps multi-stakeholder governance problems in Andaman Islands | Exclusion and ambiguity undermine legitimacy | Clarify roles, access, and communication | [11] |
| Post-conflict governance | Sri Lanka | Shows overlapping jurisdictions and weak data impede management | Recognition of local history is ethically central | Build collaboration and data-sharing mechanisms | [12] |
| Bio-rights incentives | Indonesia | Links micro-credit and conservation services | Benefit-obligation transparency improves fairness | Align livelihood support with stewardship | [16] |
| Protected-area outcomes | Brazil | Protected areas help stabilize cover but tools alone are insufficient | Formal participation can become hollow | Evaluate actual engagement and enforcement | [51] |

**Table 2. Ecological change, restoration constraints, and adaptive-management lessons**

| System/process | Study context | Core finding | Key risk/constraint | Strategic implication | Ref. |
|---|---|---|---|---|---|
| Post-aquaculture revegetation | Bali, Indonesia | Area expanded but planted Rhizophora regenerated poorly | Visible recovery may mask simplification | Favor natural recruitment and hydrology-species fit | [27] |
| Dense degradation vs sparse recovery | Muthupet Lagoon, India | Human pressure degraded dense stands while sparse cover increased | Net area change can mislead | Track condition classes, not only total area | [28] |
| Illegal logging and carbon loss | North Sumatra | UAV and field data captured sharp biomass and carbon decline | Restoration gains are reversible | Use monitoring for rapid enforcement response | [31] |
| Restoration prioritization | Mauritius | MCDA identified priority zones for restoration | Area gain alone does not define priority | Prioritize connectivity and stress profiles | [32] |
| Habitat trade-off under protection | Mai Po, Hong Kong | Mangrove expansion partly displaced mudflats | One habitat gain may reduce another | Assess habitat mosaics and complementarity | [33] |
| Secondary-forest dynamics | Bintuni Bay, Indonesia | Managed-use forests retained substantial standing stock | Production systems need regeneration evidence | Pair use regimes with long-rotation monitoring | [34] |
| Stand age and sediment microbes | Malaysia | Older restored stands had more stable bacterial networks | Early survival is not full recovery | Include belowground function in success metrics | [35] |

| | | | | | |
|---|---|---|---|---|---|
| Hydroperiod enhancement | Semiarid Mexico | Underground pipes reduced hypersalinity and improved recruitment | Planting without hydrological repair can fail | Restore tidal function before large-scale planting | [36] |
| Modeled afforestation platforms | Semiarid Mexico | Nonlinear modeling improved site selection | Generic siting reduces survival | Use site-specific ecological engineering | [37] |
| Cyclone-driven salinity stress | Indian Sundarbans | Salinity increased and blue carbon declined | Climate stress reorganizes ecosystems and livelihoods | Integrate adaptation with restoration | [38] |

**Table 3. Monitoring innovation, livelihood strategies, and emerging management implications**

| Domain | Method or issue | Illustrative finding | Management value | Ethical caution | Ref. |
|---|---|---|---|---|---|
| Species and density mapping | Sentinel-2 spectral analysis | Supports conservation planning with spatially explicit classification | Improves targeting and zoning | Needs interpretation accessible to decision-makers and communities | [29] |
| Invasive-species detection | UAV plus deep learning | Improves fine-scale identification of Derris trifoliata | Supports rapid intervention | High-resolution data can centralize technical power | [30] |
| Temporal process monitoring | Phenocams / digital repeat photography | Water and tidal effects shape apparent canopy signals | Improves ecological interpretation | Methods must respect intertidal complexity | [42] |
| Local biophysical inventory | Field assessment in Aceh and Panguil Bay | Recovery and damage coexist within landscapes | Ground-truths remote sensing and planning | Avoid remote-only judgments | [43], [44] |
| Blue-carbon policy | Climate-mitigation framing | Raises mangrove salience in national policy | Mobilizes finance and attention | Can create distributive tensions if benefits are uneven | [7], [39], [40] |
| Plural mangrove economies | Fisheries, tourism, and non-fish products | Livelihoods extend beyond timber or simple ecotourism | Broadens options for fair coastal development | Economic use must remain ecologically bounded | [19]–[24], [41], [49], [50], [53] |

## STATUS, CHANGE, AND THE PROBLEM OF MISLEADING RECOVERY NARRATIVES

One of the clearest findings across the corpus is that mangrove status cannot be reduced to a simple decline-versus-recovery storyline. At broad scale, some evidence is encouraging. Global NDVI analysis suggests that mangrove vegetation condition increased overall from 2000 to 2018, with a much larger area of significantly increasing condition than decreasing condition [4].

Global typologies of coastal wetland status also show that impacts vary in patterned ways rather than uniformly, creating relative refuges as well as multi-pressure hotspots [3]. These studies are useful because they disrupt fatalistic narratives and show that some mangrove systems remain dynamic and capable of recovery.

However, the same literature makes clear that area or greenness gains are not equivalent to functional integrity. Positive vegetation trends can coexist with salinity stress, habitat simplification, fisheries vulnerability, carbon loss, or poor governance [3], [4], [31], [33], [38], [40]. This is why the newer corpus repeatedly pushes management away from counting trees and toward evaluating system quality. In the Indian Sundarbans, for example, repeated cyclones and rising salinity were associated with reduced soil-organic blue carbon, nutrient decline, and compositional shifts toward salinity-tolerant assemblages [38]. The ethical significance is considerable. A management regime that claims success because area remains stable may still preside over declining ecological function and greater livelihood insecurity.

The Mai Po case demonstrates a related problem of internal conservation trade-off. There, mangrove expansion under protection appears to have occurred partly at the expense of mudflat habitat [33]. Expansion is therefore not automatically a conservation victory. It may benefit one habitat type while reducing another. This supports a more nuanced principle: mangrove success should be judged within habitat mosaics, not only within mangrove boundaries. The same principle matters for coastal food webs, birds, fisheries, and downstream users whose interests may not map neatly onto mangrove expansion.

Case studies at local and regional scale reinforce the argument. In Muthupet Lagoon, dense mangroves degraded under pressure from salinity, erosion, aquaculture, and other anthropogenic drivers even while sparse mangrove area increased through restoration [28]. In Bali, abandoned aquaculture landscapes showed visible mangrove expansion, but planted Rhizophora stands regenerated poorly compared with more natural assemblages [27]. These results show how easy it is to mistake visually legible vegetation gain for resilient recovery. In both cases, the literature recommends attention to regeneration, class-specific condition, and hydrological context rather than net area change alone [27], [28], [36], [37].

Subnational studies reveal additional heterogeneity. Aceh and Panguil Bay show coexistence of recovery, damage, fragmentation, and uneven regeneration within the same larger landscape [43], [44]. Mauritius adds a more recent warning: even when area expands in some zones, vegetation health can decline in others, and different spatial priorities emerge when connectivity and stress profiles are considered together [32]. North Sumatra further demonstrates how quickly gains can be reversed by renewed illegal logging, with sharp declines in biomass and carbon observed over a short interval [31]. These cases together suggest that mangrove status must be interpreted as a social-ecological signal. Ecological gain is meaningful only when it is likely to endure under existing governance, land-use pressure, and climate change [6], [31], [32], [51].

This is where environmental ethics becomes analytically useful. Misleading recovery narratives do not only create scientific error; they can misallocate resources, justify premature policy success, and obscure the burdens borne by coastal communities living with declining fisheries, weaker storm protection, or increased salinity [38]–[40]. A just management system therefore needs indicators capable of detecting hidden decline, trade-offs, and reversibility. The corpus strongly supports moving from headline recovery claims to multidimensional condition assessment.

## ENVIRONMENTAL ETHICS, GOVERNANCE, AND POLICY COHERENCE

The literature shows that ethics enters mangrove management not through abstract philosophy alone but through practical questions: who decides, who bears restrictions, whose knowledge is recognized, and what counts as a legitimate success [5]–[12], [16], [18], [39]–[41], [51], [52]. Recent global legal analysis demonstrates that many countries now provide some explicit legal protection to mangroves [5]. Yet the same literature insists that legal presence is not the same as effective or fair governance. This distinction is crucial. Law can declare value; governance determines whether that value is enacted in practice.

The GBF-alignment study deepens the point by showing that substantial high-value mangrove loss may continue outside protected areas and that many national target formulations remain insufficiently specific to halt decline by 2030 [6]. From an ethical perspective, this is both an omission problem and a distributive one. If policy protects areas that are politically convenient rather than ecologically or socially most significant, then the geography of regulation diverges from the geography of need. Ethical governance therefore requires at least three forms of fit: ecological fit between intervention and site conditions, institutional fit between rules and implementation capacity, and social fit between management systems and livelihood realities [5], [6], [8], [9], [11], [12].

The Andaman and Jaffna studies illustrate what happens when those fits fail. In the Andaman Islands, top-down management, conflicts over access and ownership, poorly regulated fisheries, and limited participation constrained governance after the 2004 earthquake and tsunami [11]. In the Jaffna Peninsula, overlapping jurisdictions, weak interaction among stakeholders, land-permit issues, limited data, and failed replanting efforts hindered management in a post-conflict setting [12]. These are not peripheral governance inconveniences. They are the mechanisms through which ecological ambitions are blocked or distorted. The ethical lesson is that mangrove conservation cannot bypass history, tenure, or institutional pluralism.

Broader policy reviews show these problems are not isolated. Coastal-wetland scholarship identifies weak adaptation, planning mismatch, and insufficient local inclusion as recurrent global issues [9]. The Mesoamerican Reef review finds a persistent disconnect between management concerns and research emphases, producing a kind of knowledge ethics problem: whose evidence is allowed to shape agendas [10]? When scientific priorities diverge from operational needs, governance risks becoming either technocratic without relevance or pragmatic without evidence. The literature therefore argues, implicitly and sometimes explicitly, for institutional coupling between science and decision-making rather than more science in the abstract [9], [10].

Participation emerges across the corpus as both normatively necessary and instrumentally useful. Bio-rights schemes in Indonesia linked micro-credit to conservation services and increased active participation [16]. Community-based restoration in the Sundarbans connected ecological recovery with livelihood support [15]. Studies from South Sulawesi, Jakarta, and other Indonesian sites show that community willingness exists but depends on land certainty, counseling, seed supply, working groups, and trust in institutions [17], [18], [22]. Exclusion, by contrast, is repeatedly associated with failure, mistrust, and weak stewardship [11], [12], [18]. Yet the review also avoids romanticizing participation. Participation can be symbolic or elite-captured. Ethical participation therefore means not merely attendance but meaningful influence, burden-sharing, and recognition.

Protected areas reveal one of the strongest paradoxes in the recent literature. Brazilian evidence suggests that protected areas can

reduce fragmentation and stabilize mangrove cover [51]. But the same study finds that governance tools such as plans and councils did not by themselves produce stronger conservation outcomes. Formal structures without active engagement may therefore become ethically hollow. Similarly, Mexico-based studies show that conservation and tourism initiatives can reorder communal space in ways that generate new tensions [13]. Protected areas remain indispensable, but their legitimacy depends on whether they protect ecosystems while respecting rights, providing alternatives, and maintaining durable relationships with affected communities.

For top-tier scholarship, the implication is clear: environmental ethics should not be appended as a concluding normative flourish. It should structure how governance performance is assessed. The most defensible mangrove governance is not the one that maximizes one metric, but the one that makes trade-offs visible, shares burdens fairly, and keeps ecological intervention accountable to those living with its consequences [5]–[7], [11], [12], [16], [18], [39]–[41], [51], [52].

## RESTORATION, REHABILITATION, AND ADAPTIVE MANAGEMENT

The restoration literature in the supplied corpus rejects any simplistic plant-more narrative. Across semiarid, urban, deltaic, and post-aquaculture settings, success depends on hydrology, geomorphology, species fit, tenure security, incentive design, and follow-up monitoring [15], [16], [22], [26], [27], [32], [35]–[37]. This is one of the strongest convergences in the review base. It also has direct ethical implications because poorly specified restoration wastes funds, labor, and community trust while creating the illusion of action.

The semiarid Mexico studies are especially instructive. Hydroperiod enhancement through underground pipes reduced hypersalinity and improved recruitment conditions, while nonlinear modeling and constructed platforms helped identify viable long-term afforestation sites [36], [37]. The underlying lesson is foundational: if hydrological dysfunction is the limiting factor, seedling campaigns alone are not only inefficient but ethically questionable. They can shift attention away from the real ecological constraint while still consuming public resources and volunteer energy.

This logic appears in other contexts as well. Urban rehabilitation in Kali Adem depended on land stability, tenure certainty, seed availability, and collaboration, not simply on planting effort [22]. Community-based restoration in the Sundarbans succeeded when livelihood support and local participation were substantive rather than symbolic [15]. Bio-rights mechanisms extended this by making the relation between stewardship and benefits more explicit [16]. Taken together, these cases move restoration from a one-off technical event to an adaptive governance arrangement that involves rights, incentives, maintenance, and local monitoring.

The ecological literature also broadens what counts as recovery. Secondary forests in Bintuni Bay retained substantial standing stock over a long rotation cycle, showing that managed-use landscapes can still be ecologically meaningful when regeneration and biomass are monitored carefully [34]. The Malaysian microbial study is even more revealing for restoration theory. Older restored stands showed more stable and diverse sediment bacterial communities than younger ones, suggesting that functional recovery continues long after visible canopy establishment [35]. This means early survival and canopy closure are insufficient proxies for success. Belowground processes, regeneration, nutrient status, and resilience must also be considered.

The Bali time-series study provides a cautionary counterexample. Mangrove expansion occurred in abandoned aquaculture ponds, yet dense Rhizophora plantings had poorer regeneration than more naturally structured assemblages [27]. The lesson is not that planting never works. It is

that standardized planting can lock ecosystems into simplified trajectories with lower self-renewal. The East Kalimantan land-suitability work and Jeneponto ecotourism sustainability assessment reinforce the same message from different angles: site conditions and carrying capacity must shape intervention design [20], [26]. A project that looks successful from a distance may still be ecologically brittle if density, salinity, pH, or substrate constraints are ignored.

Adaptive management must also confront resource use directly. The corpus does not equate ethical management with strict exclusion. Bintuni Bay discusses productive systems through regeneration and standing-stock logic [34]. Madura highlights the significance of non-fish fisheries as components of local coastal economies [41]. Batu Ampar raises the difficult politics of mangroves as raw material for charcoal production [24]. These studies show that the core ethical question is not whether use exists, but whether it is governed within ecological limits, on transparent terms, and with fair benefit distribution. Restoration that ignores local dependence may be politically brittle; utilization that ignores regeneration is ecologically irresponsible.

The most defensible restoration doctrine emerging from the corpus has five steps. First, diagnose hydrology, salinity, geomorphology, elevation, and disturbance history [26], [36]–[38]. Second, diagnose governance: tenure, access, conflict, and stakeholder relationships [11], [12], [22], [24]. Third, design interventions that match both diagnoses rather than importing generic templates [15], [16], [27], [32]. Fourth, monitor multiple recovery dimensions including condition, regeneration, carbon, and belowground processes [29], [31], [34], [35]. Fifth, revise rules and incentives over time. In effect, adaptive management is the meeting point of ecological realism and environmental ethics.

## MONITORING, MAPPING, AND ANALYTICAL INNOVATION

The supplied literature documents a striking expansion in mangrove monitoring methods. The field now combines field inventories and stakeholder inquiry with multi-temporal satellite analysis, UAV photogrammetry, deep learning, phenocams, and spatial decision-support tools [3], [4], [27]–[33], [42]–[44]. This methodological diversification matters because governance and ethics require evidence that is timely, spatially explicit, and interpretable across agencies, researchers, and communities.

At broad scale, satellite-derived indicators reveal large patterns that were previously difficult to observe. Global NDVI analysis shows broad improvement in some mangrove areas while also identifying climatic controls such as precipitation, temperature, and salinity [4]. Global wetland typologies synthesize multiple indicators into management-relevant clusters [3]. These studies improve strategic understanding, but the corpus also warns against overconfidence in single metrics. NDVI, area change, or protection status alone do not capture full ecosystem integrity [3], [4], [33], [38]. The review therefore argues for indicator pluralism: each method is useful, but only when interpreted within ecological and governance context.

Recent local and national studies show how newer tools can support action. Sentinel-2 spectral analysis was used to map species distribution and density in Surabaya [29]. In Mauritius, geospatial multi-criteria analysis combined change detection, health assessment, topography, hydrology, and freshwater access to identify restoration-priority zones [32]. In practical terms, this means remote sensing is shifting from descriptive cartography to planning support. The ethical value of such tools lies in their capacity to make prioritization decisions more transparent. If openly communicated, they can help explain why some sites are prioritized and others deferred.

UAV-based approaches extend this logic to finer scales. Deep learning on UAV images improved detection of the invasive plant Derris trifoliata [30]. UAV photogrammetry combined with field surveys captured a sharp decline in biomass and carbon after illegal logging in North Sumatra [31]. These methods reduce ambiguity in enforcement and disturbance detection. Yet they also raise questions about capacity, access, and surveillance. High-resolution data can empower management, but if control over that data remains concentrated in external institutions, new power asymmetries may emerge. The literature implies the need for participatory data governance even where it does not state it explicitly.

Phenocams add a different kind of value by clarifying temporal process. Songsom et al. show that canopy signals are influenced by tides, water background, and seasonality, reminding researchers that intertidal systems cannot be monitored as if they were purely terrestrial forests [42]. This methodological humility is critical for top-tier review writing. In mangroves, apparent greenness is shaped by water, substrate, and tidal dynamics as much as by canopy vigor. The Mai Po study similarly demonstrates that geomorphology and management history matter for interpreting expansion [33]. Good monitoring, then, is not only technologically advanced. It is also contextually literate.

Field-based ecological work remains essential. Inventories in Aceh, Panguil Bay, and Bintuni Bay demonstrate the continuing value of direct observation for species composition, regeneration, biomass, and condition assessment [34], [43], [44]. Additional biodiversity-oriented studies on actinobacteria, Streptomyces, Excoecaria responses, and snail growth broaden the monitoring horizon toward functional and organismal dimensions [45]–[48]. These studies may appear peripheral to governance at first glance, but they are not. A management regime that monitors only canopy cover risks overlooking microbial recovery, faunal response, or broader biodiversity implications.

The strongest insight here is integrative: analytical innovation is most valuable when it supports accountable decision-making. Better tools do not automatically resolve ethical questions. They can, however, reduce uncertainty, expose hidden degradation, and strengthen the evidentiary basis for more transparent management [27]–[33], [42]–[44].

## LIVELIHOODS, ECOTOURISM, AND BLUE-CARBON ECONOMIES

Mangrove research increasingly treats local economies not as external pressures alone but as constitutive parts of social-ecological systems. This is one of the most important developments in the supplied corpus. Ecosystem-services reviews in Indonesia already argued for management frameworks that connect ecological function to human wellbeing [1]. More recent blue-carbon, vulnerability, fisheries, and tourism studies deepen that argument by showing that livelihoods, adaptation, and conservation are intertwined in ways that can either reinforce or undermine one another [7], [19]–[24], [39]–[41], [49], [50], [53].

Blue carbon is perhaps the clearest example. The Indonesian review positions mangroves as major climate assets and argues for integrated policy, coordination, and finance [7]. This is politically significant because it moves mangroves from the margins of conservation policy toward the center of climate strategy. Yet the same shift creates new ethical questions. Carbon framing can channel funding and attention, but it can also privilege what is measurable over what is lived. If carbon becomes the dominant rationale, then restrictions on use, site selection, and benefit distribution require careful justification [7], [39], [40], [41]. Aggregate mitigation potential is not enough; blue-carbon policy must also be judged by whether it supports or displaces the communities already relying on these ecosystems.

The vulnerability and adaptation studies sharpen this point. Research in Palawan shows that mangrove ecosystem services are materially tied to fisheries, livelihoods, and adaptive capacity, but that vulnerability varies according to ecosystem condition, organizational support, and livelihood diversity [40]. The Bangladesh adaptation study shows that real resilience strategies combine ecosystem measures with social infrastructure such as rainwater harvesting, local filtration, cyclone shelters, crop diversification, and coastal afforestation [39]. Taken together, these studies suggest that ecosystem-based adaptation is not ethically neutral. It can either deepen local capacity or reproduce exclusion depending on how decisions are made and whose needs shape implementation.

Ecotourism literature adds another layer of complexity. Studies from Indonesia indicate that tourism can generate support for mangrove conservation, but only under conditions of carrying-capacity awareness, infrastructure control, and fair benefit sharing [19]–[23]. Research from Ecuador and the Galapagos widens the argument by showing how coastal tourism must be situated within broader integrated coastal-zone management rather than treated as a stand-alone development sector [49], [50]. The ethical issue here is subtle but important. Ecotourism is often framed as a win-win solution, yet it can intensify pressure if local communities do not capture benefits, if infrastructure fragments habitat, or if governance uses conservation branding to legitimize new exclusions. The literature therefore supports ecotourism only as a carefully governed social-ecological arrangement.

Resource-use studies further complicate any simple conservation-versus-use binary. Madura demonstrates that non-fish fisheries associated with mangroves can contribute significantly to household income and that stronger conservation can align with economic stability when resource use remains ecologically grounded [41]. Batu Ampar, by contrast, shows how dependence on mangroves for charcoal production can push systems toward degradation and force difficult policy trade-offs [24]. These cases support a more mature ethics of use: the question is not whether mangroves are used, but which uses are regenerative, governable, and fairly distributed over time.

The literature also reminds us that livelihoods are bound up with recognition and identity, not merely income. Governance and stakeholder studies indicate that management decisions are shaped by historical access, local knowledge, social memory, and the meanings attached to coastal space [11]–[13], [17], [18]. For that reason, ecosystem-services and blue-carbon frameworks are useful but insufficient on their own. A purely monetized accounting of mangrove value can miss justice, belonging, and institutional trust. Top-quality review work must therefore resist both romantic localism and technocratic valuation. The strongest pathway emerging from the corpus is a plural economy approach: mangrove policy should protect ecological function while supporting diversified, fair, and locally grounded livelihood systems [1], [7], [16], [19]–[24], [39]–[41], [49], [50], [53].

## INTEGRATIVE DISCUSSION: FROM SINGLE METRICS TO ETHICAL FIT

Across the corpus, one meta-insight stands out: the recurring failure of single-objective management. Area-based protection by itself is not enough [5], [6], [51]. Planting by itself is not enough [15], [22], [27], [36], [37]. Carbon valuation by itself is not enough [7], [39], [40]. High-resolution monitoring by itself is not enough [29]–[33], [42]. Ecotourism branding by itself is not enough [19]–[23], [49], [50]. The same pattern appears repeatedly because mangrove systems are governed through interacting ecological, economic, and political processes. When management isolates one variable, it tends either to miss trade-offs or to displace burdens elsewhere.

The review therefore proposes "ethical fit" as a synthetic concept for future mangrove scholarship. Ethical fit exists when an intervention satisfies four conditions simultaneously. First, it is ecologically appropriate: hydrology, salinity, substrate, species composition, and disturbance history support the intervention [26], [27], [35]–[38]. Second, it is institutionally feasible: the legal basis, governance capacity, monitoring system, and cross-sector coordination are adequate [5], [6], [9]–[12], [51]. Third, it is socially legitimate: affected communities are recognized, informed, and able to influence the design and distribution of costs and benefits [11], [12], [16]–[18], [39]–[41]. Fourth, it is temporally responsible: the intervention remains robust under future coastal change rather than producing short-term symbolic gains [3], [4], [32], [33], [38]. This concept helps clarify why many superficially successful interventions remain unstable. A planting campaign may be ecologically plausible but institutionally weak if tenure is unresolved. A protected area may be legally strong but socially brittle if livelihood alternatives are absent. A blue-carbon scheme may be climatically attractive but distributively unjust if restrictions fall on communities without compensation. A remote-sensing platform may be technologically advanced but democratically thin if the resulting evidence is inaccessible to local stakeholders. Ethical fit does not eliminate trade-offs, but it forces them into view.

The concept also helps reinterpret several tensions in the literature. The Mai Po case is not simply a mangrove success or mudflat failure; it is a habitat-mosaic trade-off that requires ethical justification and transparent prioritization [33]. The Brazilian protected-area study is not a refutation of protected areas; it is evidence that legal tools require more active governance to achieve social and ecological legitimacy [51]. The blue-carbon literature is not a rejection of climate framing; it is a reminder that mitigation narratives should be embedded in local justice and adaptive capacity [7], [39], [40]. In this sense, environmental ethics strengthens rather than weakens applied mangrove science because it exposes hidden assumptions about who counts, what counts, and which outcomes are acceptable.

For top-tier journal publication, this integrative framing matters methodologically as well as substantively. Many review articles remain segmented into threats, restoration, and management. The supplied corpus suggests the field is ready for a more synthetic architecture: governance should be read through ecology, ecology through livelihoods, and technology through accountability. That is the level at which mangrove review writing can make a genuinely scholarly contribution rather than offering another catalog of pressures and responses.

## RESEARCH AND POLICY AGENDA

The corpus points toward a next-generation research agenda with at least six priorities. The first is multidimensional monitoring. Future studies should combine condition, regeneration, habitat mosaics, carbon, and belowground recovery rather than relying on canopy cover or planted area alone [27], [31]–[35], [42]–[44]. This is both a scientific and governance need because misleading success indicators can entrench poor policy.

The second priority is legal-implementation research. The expansion of formal protection and biodiversity targets is a significant development, but the literature shows that law and target-setting need to be matched with enforceable mechanisms, community legitimacy, and cross-sector coordination [5], [6], [51], [52]. Comparative work should therefore move beyond cataloging legal texts toward analyzing implementation pathways and failure points.

The third priority is justice-centered blue-carbon research. Blue carbon will likely remain a dominant policy narrative. The task for future scholarship is not to reject it but to clarify when it produces fairer outcomes and when it risks enclosure, unequal reward

structures, or livelihood displacement [7], [39]–[41]. Empirical work on compensation, rights, and benefit-sharing is especially needed.

Fourth, restoration research should become more counterfactual and diagnostic. Rather than assuming intervention is beneficial, studies should ask when passive regeneration, hydrological repair, assisted regeneration, or engineered intervention is the most appropriate option [27], [32], [36], [37]. This would help reduce wasteful, symbolic, or ecologically mis-specified restoration.

Fifth, analytical innovation should be democratized. The expansion of UAVs, machine learning, and decision-support systems is valuable, but the literature suggests these tools must be embedded in transparent, interpretable, and participatory governance arrangements [29]– [33], [42]. Otherwise, technical capacity may simply widen asymmetries between outside experts and local users.

Sixth, livelihood research should move beyond timber-tourism binaries. The evidence on fisheries, non-fish products, adaptation, and integrated coastal economies shows that mangrove livelihoods are more diverse than many policy models acknowledge [19]– [24], [39]– [41], [49], [50], [53]. Stronger comparative work on plural mangrove economies could improve both justice and ecological durability.

A policy agenda follows directly from these priorities. Governments should align legal protection with driver-specific reforms, not only area-based targets [5], [6]. Restoration programs should require hydrological and tenure diagnosis before large-scale planting [15], [22], [26], [36], [37]. Protected areas should be evaluated not only by designation but by actual outcomes and relationship quality with affected communities [13], [51]. Blue-carbon initiatives should incorporate explicit social safeguards and local-benefit provisions [7], [39]–[41]. Monitoring frameworks should integrate field ecology and remote sensing in open, decision-relevant formats [29]–[33], [42]–[44]. These are not separate agendas. They are components of a single shift toward ethically accountable mangrove governance.

## CONCLUSION

The literature reviewed here shows that mangrove scholarship has entered a more mature phase. The field no longer revolves only around documenting decline or advocating restoration in generic terms. It now asks how law, livelihoods, blue carbon, monitoring systems, and ecological diagnosis are organized across dynamic and contested coastal landscapes [1]– [12], [27]– [53]. This review argues that environmental ethics should sit at the center of that conversation. Not because ethics replaces science, but because it clarifies what science is for when decisions create winners, losers, restrictions, and long-term obligations.

Three conclusions follow. First, ecological success is contingent and multidimensional. Area gain or planting output is insufficient unless accompanied by hydrological fit, regeneration, functional recovery, and resilience to renewed disturbance [27], [31]– [38], [42]– [44]. Second, governance is decisive. Legal frameworks, biodiversity targets, protected areas, and local participation all matter, but none is sufficient in isolation [5], [6], [9]– [12], [51], [52]. Third, social legitimacy is not optional. Durable mangrove futures depend on whether local communities are treated as rights-bearing actors whose livelihoods, knowledge, and vulnerabilities shape what sustainable management can mean in practice [11], [12], [16]– [18], [39]– [41].

The broader implication is that future mangrove review writing should abandon single-objective narratives. The most defensible path is an integrative one in which restoration quality, livelihood justice, blue-carbon policy, and transparent monitoring are treated as coequal foundations of management. That is also where the strongest contribution of environmental ethics lies. It helps transform mangrove management from

a set of technical interventions into a more accountable practice of governing social-ecological futures.

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