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Ecosystem-Based Marine Fisheries Management Model for Resource Sustainability

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Abstract

Marine fisheries face increasing pressure from overexploitation, climate variability, and ecosystem degradation. Conventional single-species management approaches have proven insufficient to address these complex challenges. Ecosystem-Based Fisheries Management (EBFM) has emerged as an integrated framework that considers ecological, environmental, economic, and social dimensions of fisheries systems. This study aims to develop a conceptual model of ecosystem-based marine fisheries management to support long-term resource sustainability. The study applied a qualitative systematic review combined with comparative analysis of empirical EBFM case studies from tropical and temperate marine ecosystems. Data were collected from peer-reviewed international and national journals published between 2008 and 2025. The analysis focused on ecosystem indicators, management domains, governance mechanisms, and adaptive strategies. The results show that effective EBFM models consistently integrate habitat protection, biodiversity monitoring, stakeholder participation, and climate-responsive management tools. Tropical fisheries require stronger emphasis on spatial planning and community-based governance due to high ecological sensitivity and socio-economic dependence. The proposed model synthesizes ecological thresholds, adaptive management cycles, and participatory decision-making processes. This model provides a practical framework for policymakers and fisheries managers to enhance resilience and sustainability of marine fisheries systems. The study contributes to the operationalization of EBFM in developing country contexts.

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Introduction

Marine fisheries constitute a vital component of global food systems and coastal economies. They supply animal protein for millions of people and sustain livelihoods in coastal and island communities. Despite this importance, many marine fisheries face persistent declines in stock biomass, habitat quality, and ecosystem integrity. Overfishing, destructive fishing practices, climate variability, and weak governance structures interact to intensify pressure on marine ecosystems. These pressures challenge the capacity of conventional fisheries management to achieve sustainability objectives.

Traditional fisheries management has historically emphasized single-species stock assessment and yield optimization. Management instruments often rely on biological reference points derived from target

species population dynamics. While effective in relatively simple systems, this approach inadequately captures ecological interactions, habitat dependencies, and cumulative human impacts. Crowder et al. (2008) demonstrated that single-species management frequently overlooks bycatch, trophic relationships, and ecosystem feedbacks, which can undermine long-term stock recovery and ecosystem stability. As marine ecosystems function as interconnected systems, management strategies that isolate species risk producing unintended ecological consequences.

Ecosystem-Based Fisheries Management has emerged as a response to these limitations. EBFM broadens the scope of management by integrating ecological processes, habitat conditions, and human activities into decision-making frameworks. Trochta et al. (2018) emphasized that EBFM seeks to maintain ecosystem structure, function, and productivity while allowing sustainable resource use. Rather than maximizing yield from individual stocks, EBFM prioritizes ecological thresholds and system resilience. This shift reflects an evolution in fisheries science toward systems-based thinking and precautionary governance.

The relevance of EBFM has increased under accelerating climate change. Ocean warming, altered circulation patterns, and increased frequency of extreme events reshape marine productivity and species distributions. Holsman et al. (2020) provided empirical evidence that ecosystem-based approaches reduce the risk of climate-driven stock collapse by incorporating environmental indicators into harvest strategies. Climate-responsive management allows fisheries institutions to adjust rules as ecosystem conditions change, rather than relying on static reference points that may lose relevance under shifting baselines.

Empirical studies also demonstrate the importance of spatial and temporal ecosystem variability in shaping fish communities. Wanjari et al. (2025) showed that fish diversity patterns respond strongly to environmental parameters across seasons and locations in tropical systems. Although conducted in a reservoir context, these findings highlight a broader principle applicable to marine fisheries. Ecosystem variability influences species composition, recruitment success, and productivity. Management frameworks that fail to integrate such variability risk misaligning exploitation levels with ecosystem capacity.

Governance plays a central role in the effectiveness of EBFM. Ecosystem-based approaches require coordination across institutions, sectors, and stakeholder groups. Jones and Seara (2020) argued that stakeholder participation enhances legitimacy, compliance, and adaptive capacity in fisheries management. Fishers possess contextual knowledge that complements scientific monitoring, particularly in data-limited environments. Participatory governance enables co-production of knowledge and supports adaptive decision-making processes aligned with ecosystem dynamics.

Operationalization of EBFM also depends on institutional clarity and decision rules that translate ecosystem information into management action. Dolan et al. (2016) described EBFM as a continuum rather than a fixed endpoint, ranging from traditional management with ecosystem considerations to fully integrated ecosystem governance. This perspective underscores the need for practical models that align scientific indicators with policy instruments. Without clear operational frameworks, EBFM risks remaining a normative concept rather than an implementable management approach.

In Indonesia, ecosystem-based fisheries management has gained formal recognition within national policy discourse. The diversity of marine ecosystems and high socio-economic dependence on fisheries create strong incentives for adopting ecosystem-based approaches. Case studies reveal varied implementation outcomes across regions. Kirana et al. (2025) reported that ecosystem-based innovation in the Karimunjawa ecosystem improved fisheries resilience, yet highlighted uneven institutional capacity and monitoring infrastructure. These findings reflect broader challenges in translating EBFM principles into consistent practice in developing country contexts.

Empirical assessments from Indonesian fisheries further demonstrate the potential benefits of ecosystem-based approaches. Fauzan et al. (2023) showed that sustainability assessments incorporating

ecosystem dimensions provided a more comprehensive evaluation of stock status and management performance. Studies in Kupang fisheries indicated that ecosystem-based management improved alignment between ecological conditions and economic outcomes when applied across resource and economic domains (Missa et al., 2025; Tefbana et al., 2025). These studies suggest that EBFM can support both conservation and livelihood objectives when implemented coherently.

Despite expanding literature, gaps remain in the development of conceptual models tailored to tropical marine fisheries. Many existing frameworks emphasize ecological indicators but insufficiently integrate governance mechanisms and adaptive management cycles. Hemraj and Carstensen (2025) highlighted the importance of detecting ecological tipping points, yet translating such detection into management action requires institutional readiness and participatory processes. Similarly, ecosystem modeling studies emphasize system complexity but often lack clear pathways for policy implementation (Grüss et al., 2017).

Another limitation concerns the contextual specificity of EBFM models. Frameworks developed in temperate, data-rich fisheries may not directly apply to tropical systems characterized by high biodiversity, multi-gear fisheries, and limited data availability. Tropical fisheries often involve small-scale actors with strong dependence on local ecosystems. Spatial planning and community-based governance therefore play a more prominent role in these contexts. Caputi et al. (2025) noted that successful EBFM implementation depends on aligning management tools with ecological and socio-economic characteristics of each fishery.

This study addresses these gaps by developing a conceptual ecosystem-based marine fisheries management model focused on resource sustainability. The model synthesizes empirical findings from international and Indonesian case studies to identify core components of effective EBFM. Emphasis is placed on ecosystem indicators, adaptive management cycles, participatory governance, and climate-responsive strategies. By integrating these elements, the proposed model aims to support practical implementation rather than abstract conceptualization.

The contribution of this study lies in its focus on operational relevance for tropical marine fisheries. Rather than proposing new indicators or methods, it consolidates established EBFM principles into a coherent management structure grounded in empirical evidence. This approach aligns with the need for management frameworks that are scientifically robust, institutionally feasible, and adaptable to environmental change. The resulting model is intended to assist policymakers and fisheries managers in aligning exploitation practices with ecosystem limits and long-term sustainability objectives.

Methods

Research Design and Approach

This study applied a qualitative research design using a systematic literature review combined with comparative analysis. This approach was selected to synthesize empirical evidence and conceptual developments related to ecosystem-based fisheries management in marine systems. A qualitative design is appropriate because the objective of the study is to construct a conceptual management model rather than to test statistical relationships or estimate numerical parameters. The focus lies on identifying recurring patterns, management components, and governance mechanisms that support sustainability outcomes in marine fisheries.

The systematic review framework ensured a transparent and replicable process for identifying, screening, and analyzing relevant literature. Comparative analysis was used to examine similarities and differences across case studies from tropical and temperate marine ecosystems. This combination allowed the study to integrate theoretical perspectives with applied management experiences.

Data Sources and Selection Criteria

Data were derived exclusively from peer-reviewed journal articles, conference proceedings, and policy-oriented scientific publications related to ecosystem-based fisheries management. The literature covered the publication period from 2008 to 2025, reflecting the evolution of EBFM concepts and implementation practices over time. Sources included international journals such as Fisheries Research, Biological Reviews, Nature Communications, and relevant national Indonesian journals focusing on fisheries management and sustainability.

The selection process applied inclusion criteria based on relevance to marine fisheries, explicit use of ecosystem-based management principles, and empirical or applied orientation. Studies addressing ecosystem indicators, adaptive management, governance structures, or stakeholder participation were prioritized. Publications focusing solely on single-species management without ecosystem considerations were excluded. This screening ensured that all reviewed materials directly informed the objectives of model development.

Data Extraction and Analytical Procedure

Content analysis was employed to systematically extract key information from the selected literature. Extracted elements included ecosystem indicators, management domains, governance arrangements, adaptive strategies, and implementation challenges. Each study was reviewed to identify how ecological information was translated into management decisions and how institutional mechanisms supported or constrained EBFM implementation.

Comparative analysis was conducted across case studies to identify recurring patterns and critical success factors. Tropical and temperate fisheries cases were examined separately to capture contextual differences related to biodiversity, socio-economic dependence, and data availability. This comparative perspective allowed the study to assess which EBFM components were context-specific and which were broadly applicable across marine systems.

Model Synthesis

The synthesis stage integrated findings from the content and comparative analyses into a conceptual ecosystem-based marine fisheries management model. The model development followed a structured process. First, core ecosystem domains were identified, including biological, environmental, and habitat dimensions. Second, governance and institutional components were mapped to illustrate decision-making structures and stakeholder roles. Third, adaptive management cycles were incorporated to reflect feedback between monitoring, evaluation, and policy adjustment.

The synthesis did not introduce new indicators or analytical tools. Instead, it consolidated established components documented in the reviewed literature. Emphasis was placed on aligning ecological thresholds with governance mechanisms to ensure operational relevance. The resulting model reflects an integrative framework that links ecosystem monitoring, participatory governance, and adaptive policy responses.

Validity and Reliability Considerations

To enhance analytical rigor, the study applied consistent criteria during literature selection and data extraction. Cross-checking of themes across multiple sources reduced the risk of interpretive bias. The use of well-established and widely cited studies strengthened conceptual validity. Reliability was supported through transparent documentation of analytical steps, enabling replication by future researchers using similar literature sets.

Although the study relies on secondary data, the systematic and comparative design provides a robust foundation for conceptual model development. Limitations related to variability in study contexts and methodologies were addressed by focusing on convergent findings rather than isolated results.

Results and Discussion

Multidimensional Ecosystem Indicators in EBFM Implementation

The reviewed studies consistently indicate that effective ecosystem-based fisheries management depends on the integration of multidimensional ecosystem indicators. These indicators do not operate independently but interact to determine ecosystem status and management performance. Empirical findings emphasize biological, environmental, and habitat-related indicators as the primary ecological foundation of EBFM.

Wanjari et al. (2025) demonstrated that species diversity and assemblage structure respond strongly to spatial and temporal environmental variability. This pattern confirms that fisheries productivity cannot be evaluated using static biological indicators alone. Similarly, Holsman et al. (2020) showed that incorporating environmental drivers into management decisions reduces vulnerability to climate-induced stock collapse. These findings highlight the empirical relevance of ecosystem indicators as operational inputs rather than descriptive metrics. Table 1 summarizes ecosystem indicator domains identified across the reviewed studies.

Table 1. Ecosystem Indicator Domains Applied in EBFM Studies

Indicator Domain	Empirical Focus	Management Relevance
Biological	Species diversity, trophic structure, stock status	Detects ecosystem balance and fishing pressure
Environmental	Temperature, productivity, seasonal variability	Supports climate-responsive management
Habitat	Habitat condition, spatial distribution	Guides spatial planning and protection
Socio-ecological	Fishery dependence, interaction intensity	Aligns exploitation with ecosystem capacity

These domains reflect convergence across tropical and temperate fisheries. However, tropical systems require stronger emphasis on spatial heterogeneity and seasonal dynamics due to higher biodiversity and ecological sensitivity.

Governance Structures and Adaptive Capacity

Governance emerged as a decisive factor influencing EBFM effectiveness. Empirical evidence indicates that fisheries with clearly defined institutional roles and adaptive decision frameworks achieve better sustainability outcomes. Jones and Seara (2020) demonstrated that participatory governance improves compliance and management legitimacy. This finding is reinforced by Indonesian case studies where stakeholder engagement contributed to improved alignment between ecological conditions and management measures.

Kruse et al. (2025) illustrated how ecosystem indicators informed harvest control rules and spatial management in Bering Sea crab fisheries. Although operating in a temperate context, the governance logic remains relevant. Adaptive decision-making based on ecosystem feedback enables timely policy adjustment and reduces ecological risk. Table 2 presents governance and management components consistently associated with effective EBFM.

Table 2. Governance and Management Components Supporting EBFM

Component	Empirical Evidence	Functional Role
Institutional clarity	Defined management authority	Ensures accountability
Stakeholder participation	Local knowledge integration	Enhances compliance
Adaptive decision rules	Feedback-based adjustments	Responds to ecosystem change
Cross-sector coordination	Policy coherence	Reduces management conflict

These components confirm that EBFM effectiveness depends not only on ecological knowledge but also on institutional capacity to act on that knowledge.

Empirical Outcomes from Indonesian Fisheries

Empirical studies from Indonesian fisheries demonstrate positive outcomes when EBFM principles are applied consistently. Fauzan et al. (2023) showed that ecosystem-based assessments provide a more comprehensive evaluation of sustainability compared to single-domain approaches. Studies in Kupang fisheries reported improved alignment between ecological indicators and economic performance across resource and economic domains (Missa et al., 2025; Tefbana et al., 2025).

Kirana et al. (2025) further highlighted that ecosystem-based innovation increased fisheries resilience in the Karimunjawa ecosystem. However, the study also identified uneven institutional capacity as a limiting factor. These findings confirm that EBFM success depends on balanced development of monitoring systems and governance structures.

Synthesis of the Ecosystem-Based Management Model

Based on the comparative analysis, a conceptual ecosystem-based marine fisheries management model was synthesized. The model integrates ecosystem indicators, adaptive management cycles, participatory governance, and sustainability outcomes. It reflects empirical convergence across the reviewed studies and emphasizes operational feasibility rather than theoretical abstraction.

The model positions ecosystem indicators as the entry point for management, feeding into monitoring and assessment processes. Adaptive management mechanisms translate ecosystem feedback into policy adjustment. Participatory governance ensures legitimacy and compliance, while sustainability outcomes serve as evaluative benchmarks.

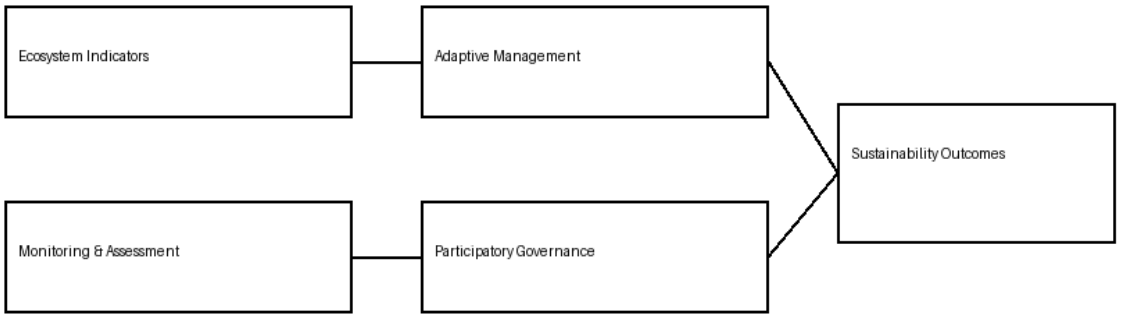

Figure 1. illustrates the synthesized EBFM model.

This structure aligns with the continuum perspective of EBFM proposed by Dolan et al. (2016) and the implementation-oriented recommendations of Grüss et al. (2017). The model supports sustainability by explicitly linking ecological limits with governance responses.

Conclusion

This study confirms that ecosystem-based marine fisheries management provides a coherent and effective framework for achieving long-term resource sustainability. The findings show that fisheries management becomes more resilient when ecological indicators, governance mechanisms, and adaptive decision processes are integrated within a single management structure. Ecosystem indicators function as critical inputs that inform management responses to environmental variability and fishing pressure.

The analysis demonstrates that adaptive management plays a central role in translating ecosystem information into policy action. Fisheries systems that apply feedback-based decision rules are better equipped to respond to climate-driven changes and ecosystem uncertainty. Stakeholder participation further strengthens management effectiveness by improving legitimacy, compliance, and the relevance of monitoring processes, particularly in data-limited fisheries.

Empirical evidence from Indonesian and international case studies indicates that ecosystem-based approaches improve alignment between ecological conditions and socio-economic objectives when applied consistently across management domains. However, the effectiveness of EBFM depends on institutional capacity, coordination, and clarity of management authority. Weak governance structures limit the operationalization of ecosystem information, even when ecological data are available.

The conceptual model developed in this study synthesizes established EBFM components into an operational framework suitable for tropical marine fisheries. By linking ecosystem monitoring, adaptive management cycles, and participatory governance, the model provides practical guidance for policymakers and fisheries managers. Strengthening monitoring systems and institutional readiness is essential to support the successful implementation of ecosystem-based fisheries management and ensure long-term sustainability of marine resources.

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