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A Bibliometric and Systematic Literature Review of Seagrass Conservation for Sustainable Management

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Abstract

Seagrass ecosystems play a crucial role in supporting coastal resilience, maintaining biodiversity, and storing blue carbon, making them vital components of sustainable coastal management. This study uses a Systematic Literature Review (SLR) combined with bibliometric analysis to examine global research trends, thematic areas, and policy gaps in seagrass conservation between 2000 and 2025. Drawing on data from Dimensions.ai and Google Scholar, 500 publications were systematically reviewed in accordance with PRISMA guidelines, and 37 peer-reviewed studies were identified as highly relevant. Bibliometric mapping with VOSviewer revealed four key research clusters: ecological processes, blue carbon and climate mitigation, governance and stakeholder engagement, and socio-economic dimensions. The results show that studies on ecology and blue carbon dominate the literature, while adaptive management and policy integration remain limited—particularly in tropical regions such as Indonesia. This study underscores the importance of developing community-based and context-specific approaches that connect ecological research with socio-economic priorities to strengthen seagrass conservation and advance sustainable coastal development.

Keywords: seagrass conservation; management sustainability; systematic literature review; bibliometric analysis

INTRODUCTION

Seagrass ecosystems are increasingly recognized as a core component of blue carbon, coastal ecosystem services, and nature-based solutions for climate change. Numerous studies demonstrate that seagrass meadows play a significant role in carbon storage, shoreline protection, and the support of biodiversity and fisheries productivity (Creed et al., 2023; Himes-Cornell et al., 2018; Heckwolf et al., 2020). Despite these benefits, seagrass is also identified as one of the most rapidly degrading coastal ecosystems globally, driven by cumulative pressures from anthropogenic activities and climate change, resulting in substantial historical losses across many regions (Green et al., 2021; Mwikamba et al., 2024; Stankovic et al., 2023). This dual role highlights the urgency of strengthening seagrass conservation and sustainable management, particularly in coastal communities that depend heavily on its ecosystem services.

The tropical Indo-Pacific region, including Indonesia, represents a global hotspot of seagrass biodiversity with extensive spatial coverage and high species richness. However, research in Southeast Asia indicates that seagrass meadows face multiple stressors, such as coastal land-use change, unregulated tourism, increased sedimentation and eutrophication, and destructive fishing practices (Al-Asif et al., 2023; Satrya et al., 2024). At the same time, the growing emphasis on blue carbon and nature-based solutions has elevated seagrass from a purely ecological concern to a strategic asset in climate policy and sustainable coastal development (Herrera-Silveira et al., 2020; Stankovic et al., 2023). Nevertheless, scientific evidence on seagrass conservation and management remains fragmented across spatial scales, limiting its direct applicability to local governance and decision-making.

West Nusa Tenggara (NTB) Province in Indonesia is characterized by small island systems where seagrass ecosystems support small-scale fisheries and offer strong potential for marine ecotourism. While numerous biophysical studies have been conducted in Indonesia and Southeast Asia, most are localized case studies, making it challenging to synthesize conservation and management insights at the provincial scale (Mwikamba et al., 2024; Satrya et al., 2024). Furthermore, relatively few studies explicitly link seagrass conservation to socio-economic outcomes and regional policy design, creating a gap between scientific knowledge and practical governance needs (Brooks et al., 2020; Creed et al., 2023).

To address this gap, this study applies a PRISMA-based Systematic Literature Review (SLR) using the keywords "conservation and seagrass" and "conservation seagrass," while excluding studies conducted at global, national, and NTB provincial scales. A total of 50 articles were selected, predominantly representing local and

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regional studies from the United Kingdom, the Mediterranean, Africa, Southeast Asia, and Australia (Al-Asif et al., 2023; Green et al., 2021; Lekammudiyanse et al., 2024; Mwikamba et al., 2024; Pansini et al., 2022; Satrya et al., 2024). By integrating SLR and bibliometric analysis (Lyford et al., 2025; Moreira-Saporiti et al., 2023), this paper aims to: (1) examine the evolution of research trends on seagrass conservation and sustainable management across spatial scales relevant to NTB, (2) identify dominant thematic clusters and collaboration patterns within seagrass conservation research, and (3) highlight key knowledge gaps and policy challenges to inform governance strategies for strengthening seagrass ecosystem management in Indonesia, particularly in West Nusa Tenggara Province.

MATERIALS AND METHODS

Time and Location

This research was undertaken over three weeks in November 2025. Given that the study employed a Systematic Literature Review (SLR) and bibliometric analysis, it did not require a defined physical field site. Accordingly, all stages of data collection, screening, extraction, and analysis were conducted remotely using secondary data retrieved from established academic databases, namely Scopus, Google Scholar, and Dimensions.ai.

Research Design

This study applies a PRISMA-guided Systematic Literature Review (SLR) integrated with a bibliometric analysis to map research developments on seagrass conservation and sustainable seagrass management. The SLR was selected to ensure a systematic, transparent, and replicable process for identifying, screening, and synthesizing relevant studies. Literature searches used the keywords “conservation and seagrass,” “conservation seagrass,” and “sustainable management seagrass,” combined with Boolean operators, and were conducted in Scopus and Google Scholar. Screening followed PRISMA stages: duplicate removal, title/abstract screening, and full-text eligibility assessment, resulting in a final set of highly relevant articles. For the bibliometric component, records were additionally retrieved from Dimensions.ai using the keywords “seagrass conservation” and “management. sustainability.” The dataset was visualized in VOSviewer to examine network relationships, thematic distribution, and keyword density, then interpreted through qualitative content analysis to contextualize patterns and identify research gaps.

Population and Sample. The population comprised scientific articles on seagrass conservation and sustainable management indexed in international databases. The sample consisted of peer-reviewed journal articles retrieved from Dimensions.ai and Google Scholar using the keywords “seagrass conservation,” “seagrass management,” and “sustainable management of seagrass,” selected according to PRISMA-based inclusion criteria.

Research Procedure

This study employed a Systematic Literature Review (SLR) based on the PRISMA framework, integrated with bibliometric analysis. The procedure consisted of the following stages: (1) searching for articles in Dimensions.ai and Google Scholar using predetermined keywords; (2) removing duplicate records; (3) screening titles and abstracts; and (4) conducting full-text eligibility assessments to obtain the final list of relevant articles. The metadata of the selected articles were then exported and prepared for analysis using VOSviewer.

Data Analysis

The SLR analysis was conducted qualitatively to synthesize key themes, methodological approaches, and main findings related to seagrass conservation and sustainable management. The bibliometric analysis, performed using VOSviewer, was applied to visualize citation networks, author collaborations, and keyword co-occurrence patterns. These visualizations revealed thematic clusters, research trends, and knowledge gaps in seagrass conservation and sustainable seagrass management. The integration of both analyses provided a comprehensive overview of the current knowledge landscape and the future research directions in seagrass conservation studies.

RESULTS AND DISCUSSION

VOSviewer Analysis Results

The analysis using VOSviewer produced a bibliometric visualization map that illustrates four main research clusters on global seagrass ecosystem studies. The red cluster represents ecological research focusing on the physiological and morphological aspects of seagrass species such as Zostera marina and Posidonia oceanica, as well as their responses to environmental stressors including temperature, eutrophication, and sedimentation. The green cluster highlights the blue carbon theme, emphasizing the role of seagrass in carbon storage and climate change mitigation. Meanwhile, the blue cluster demonstrates strong connections to policy aspects, stakeholder engagement, and nature-based solutions, indicating that seagrass management is increasingly shifting toward adaptive and collaborative governance frameworks. The yellow cluster reflects global contexts, including the impacts of human activities, climate change, and the geographical dynamics of tropical coastal regions, particularly in Southeast Asia.

Overall, the visualization results indicate that seagrass research is inherently multidisciplinary, integrating ecological science, carbon mitigation, governance and policy studies, and socio-economic dimensions. This integration underscores the growing recognition of seagrass ecosystems not only as ecological assets but also as critical components of global sustainability and climate resilience strategies.

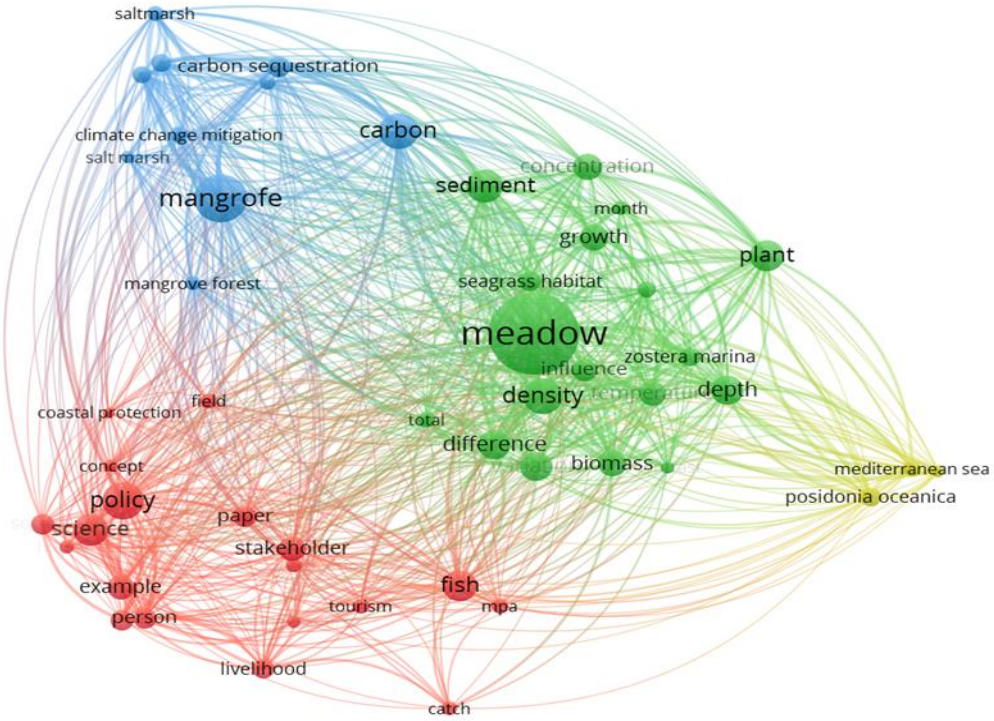

Figure 1. Network Visualization

From the VOSviewer map, it is evident that research on seagrass conservation and sustainability management forms several major, interconnected clusters. The green cluster, centered on the term "meadow," along with other key nodes such as density, biomass, sediment, depth, growth, seagrass habitat, and plant, reflects a primary focus on the ecological and biophysical functions of seagrass meadows. This indicates that most publications remain oriented toward measuring ecosystem structure and function (including density, biomass, sediment composition, depth, and temperature) as a foundation for understanding the condition and resilience of seagrass ecosystems, an essential basis for conservation and determining ecological carrying capacity in sustainable management.

In the upper-left area, the blue cluster, dominated by terms such as mangrove, salt marsh, carbon sequestration, climate change mitigation, and coastal protection, demonstrates that seagrass conservation is frequently examined within the broader framework of blue carbon and coastal protection alongside mangroves and salt marshes. This suggests that seagrass conservation in the literature does not stand alone but is positioned as part of a coastal ecosystem mosaic that contributes to carbon sequestration and climate change mitigation. The close interconnection between the blue and green clusters further indicates that the carbon storage function and coastal protection capacity of seagrass ecosystems are highly dependent on their biophysical condition.

The red cluster, located at the lower section of the map, includes keywords such as policy, science, stakeholder, tourism, livelihood, fish, catch, and MPA (Marine Protected Area), representing the socio-economic and governance dimensions. The presence of these terms suggests that conservation and sustainable management issues are increasingly being linked to livelihoods, tourism, and formal policy instruments. However, the relatively smaller size of the "policy" node and other management-related terms, compared to ecological nodes, implies that aspects of governance and practical management remain underexplored relative to purely biophysical studies.

Meanwhile, the yellow cluster on the right side (e.g., Mediterranean Sea, Posidonia oceanica) highlights the concentration of regional case studies, particularly in the Mediterranean Sea, focusing on the key species Posidonia oceanica. The dominance of this geographic focus suggests a form of geographic bias, as detailed scientific evidence is more abundant in specific regions rather than in tropical areas such as Indonesia or West Nusa Tenggara (NTB). When linked to the theme of seagrass conservation and sustainable management, the map conveys two main insights: (1) the biophysical foundation and blue carbon framework are well established, but (2) there remain significant gaps in adaptive management,

policy integration, and socio-economic contextualization in developing regions. This is where the present research can contribute by synthesizing lessons from these global clusters and translating them into more context-specific recommendations for seagrass governance and conservation policy in NTB and Indonesia.

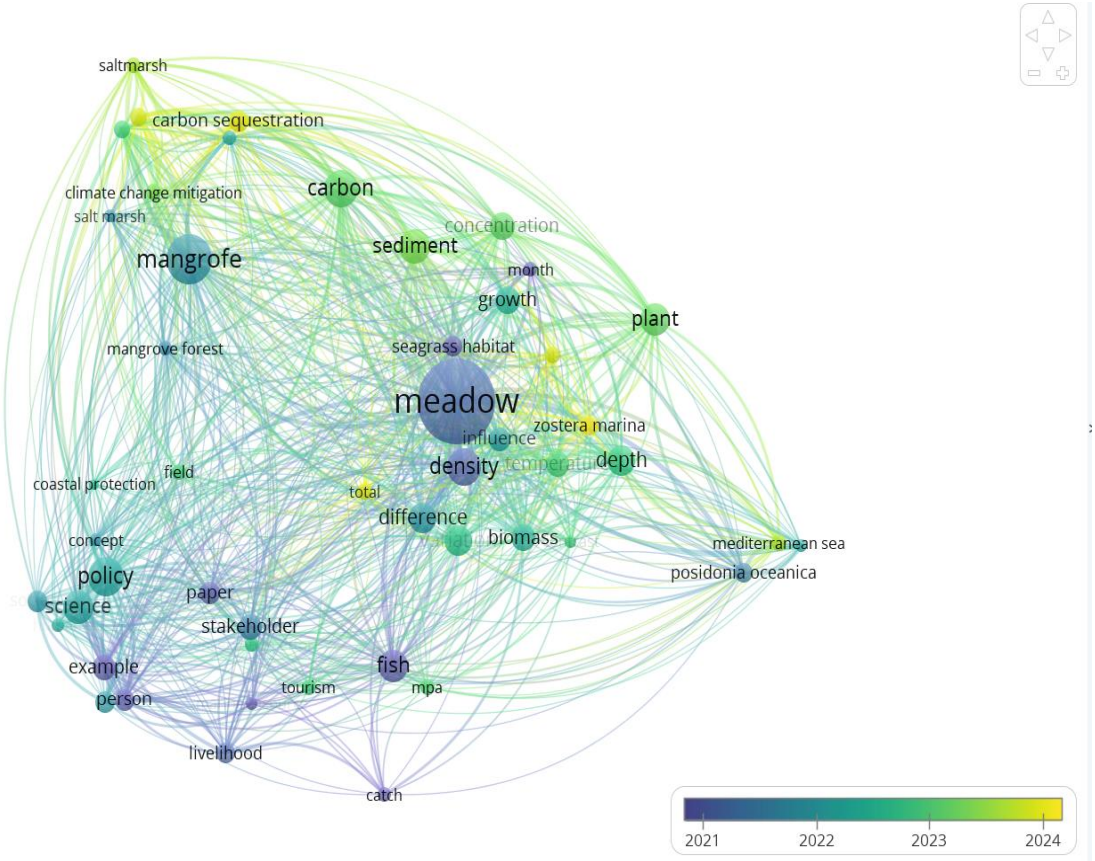

Figure 2. Overlay Visualization

The VOSviewer overlay map illustrates a dense network of keywords, with “meadow” serving as the central node. This term is strongly linked to related concepts such as density, biomass, sediment, depth, plant, seagrass habitat, and carbon. The color variations, ranging from blue to green-yellow, indicate that ecological and biophysical studies on seagrass meadows have been continuously conducted from 2021 to 2024, with no clear temporal gap. This suggests that research on ecosystem structure and function, including density, biomass, sediment, depth, temperature, and growth, remains the primary focus and serves as the scientific foundation for various seagrass conservation and sustainable management efforts.

In the upper-left area, a cluster associated with the blue carbon concept is observed, characterized by keywords such as carbon sequestration, climate change mitigation, coastal protection, mangrove, and salt marsh. Many nodes in this cluster appear in green–yellow shades, indicating that topics related to blue carbon and climate change mitigation have received increasing research attention in recent years. This pattern suggests that seagrass conservation is not viewed in isolation but as part of a broader mosaic of coastal ecosystems, including mangroves and salt marshes, that play vital roles in carbon sequestration and shoreline protection. The close connection between the blue carbon cluster and the seagrass ecology cluster further reinforces that the biophysical quality of seagrass meadows largely determines their contribution to climate change mitigation.

The lower section of the map displays keywords such as policy, stakeholder, livelihood, tourism, fish, and MPA (Marine Protected Area), representing the socio-economic and governance dimensions. These nodes tend to be smaller in size and appear mostly in blue–green tones, suggesting that studies on policy, stakeholder participation, livelihoods, and tourism are emerging but remain less dominant compared to biophysical and blue carbon research. On the right, the terms Mediterranean Sea and Posidonia oceanica highlight a strong focus on case studies in the Mediterranean region, indicating a geographical bias in the existing literature. Overall, this map illustrates that the ecological and blue-carbon knowledge base is relatively well-established. At the same time, adaptive management, policy integration, and socio-economic contexts, particularly in tropical regions such as Indonesia, still offer significant opportunities for further research.

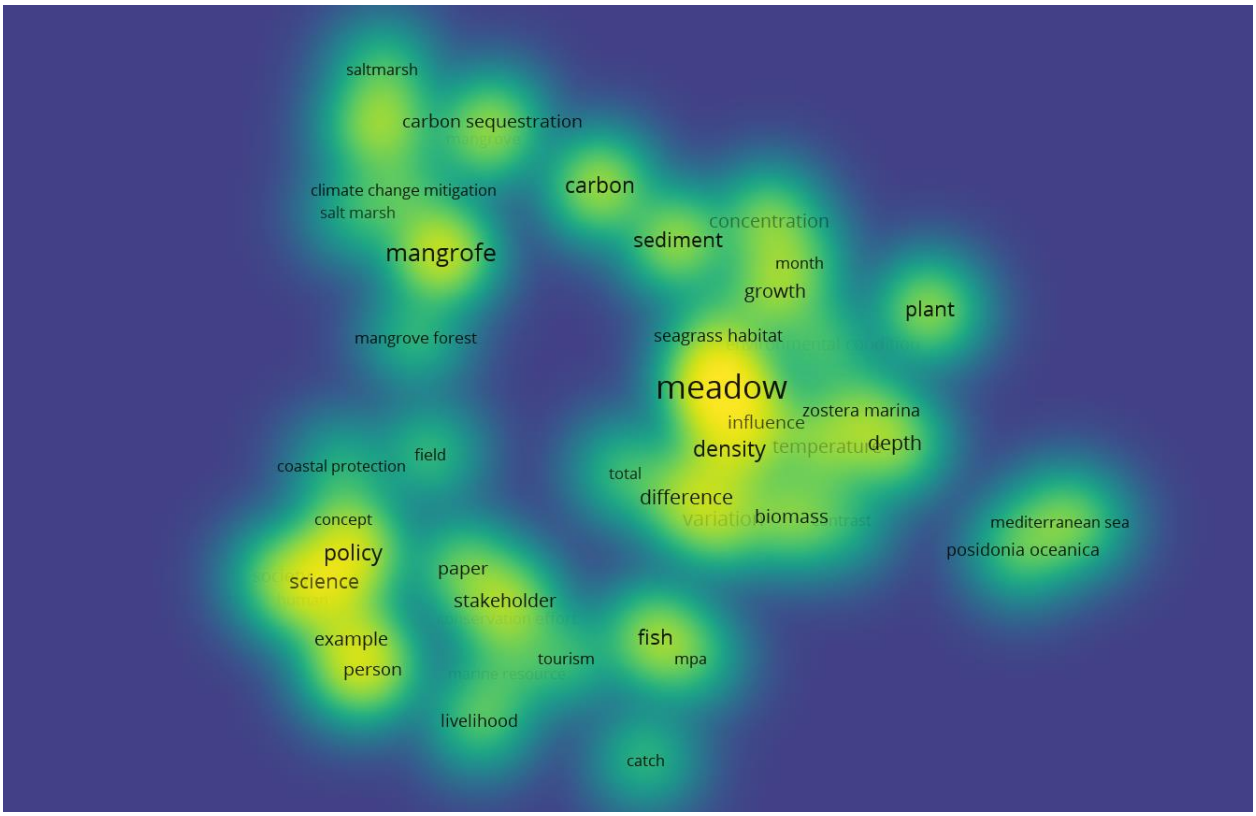

Figure 3. Density Visualization

The density visualization map illustrates the distribution of keyword concentration within the literature on seagrass research. The yellow color represents the most frequently occurring keywords that serve as central research foci, while green indicates moderate frequency and blue–purple signifies low frequency. It is clear that the term "meadow," along with related keywords such as density, biomass, depth, sediment, and carbon, falls within the brightest yellow zone. This indicates that most studies continue to focus on the biophysical condition of seagrass meadows, examining biomass density, the influence of depth and sediment on seagrass growth, and their relationship to the carbon cycle. This ecological foundation underpins conservation efforts and sustainable management initiatives.

On the left side of the map, another dense area appears around the keywords mangrove, salt marsh, carbon sequestration, and climate change mitigation, which are also highlighted in light yellow–green tones. This suggests that seagrass is frequently studied alongside mangroves and salt marshes within the broader blue-carbon and climate-change-mitigation framework. In other words, seagrass conservation in the international literature is not viewed as an isolated topic but rather as part of an interconnected coastal ecosystem network that collectively contributes to carbon sequestration and shoreline protection. In the lower part of the map, the clustering of keywords such as policy, science, stakeholder, livelihood, tourism, fish, and MPA (Marine Protected Area) indicates growing attention toward the governance and socio-economic dimensions, specifically policy development, stakeholder engagement, livelihoods, and marine conservation areas. However, their research intensity remains lower than that of purely biophysical and blue carbon studies.

On the right side, the noticeable density of keywords such as Mediterranean Sea and Posidonia oceanica reveals that a significant portion of in-depth studies has been conducted in the Mediterranean region, focusing on particular seagrass species. This suggests a geographical bias, with more detailed scientific evidence originating from these regions rather than from tropical areas such as Indonesia or West Nusa Tenggara (NTB). For studies on seagrass conservation and sustainable management with a focus on NTB, this pattern presents an important opportunity: future research can build upon the global body of knowledge on seagrass ecology and blue carbon while addressing existing gaps in policy, governance, and socio-economic contexts within tropical regions that have thus far received comparatively limited attention in the global scientific landscape.

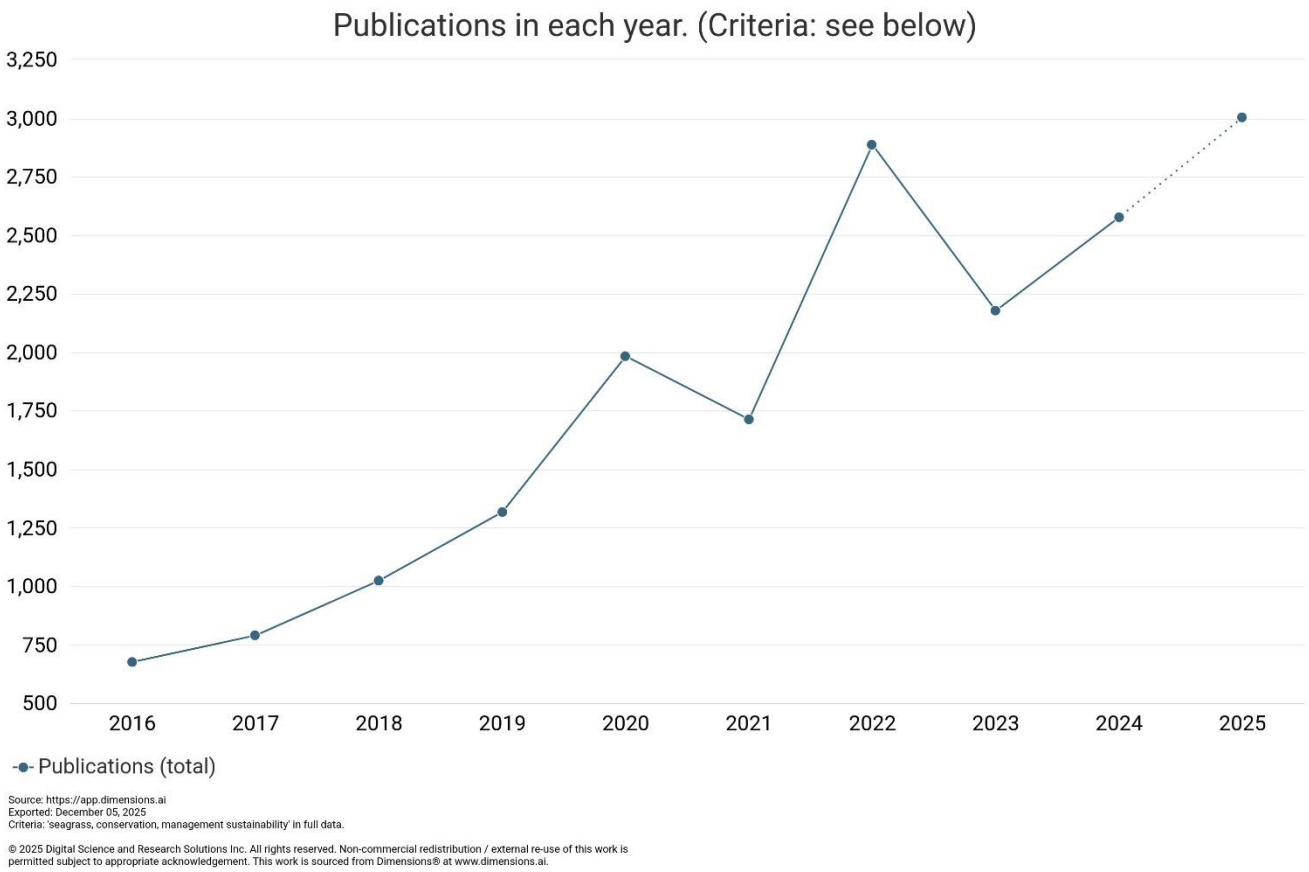

Figure 4. Research Trends with the Keywords *Seagrass Conservation* and *Management Sustainability*

The annual publication graph for the keywords seagrass, conservation, and management sustainability shows a consistent, substantial upward trend from 2016 to 2025, with a significant surge after 2019, when the number of publications nearly doubled, reaching nearly 2,000. The output then peaked at approximately 3,000 publications in 2022, declined slightly in 2023, and began to rise again in 2024, with projections indicating it will exceed 3,000 by 2025. This pattern indicates a substantial escalation in scientific interest in seagrass conservation and sustainable management, aligning with the global agenda on blue carbon, climate change, and the Sustainable Development Goals (SDGs). Minor year-to-year fluctuations can be understood as a natural part of funding cycles and shifts in research focus; however, the overall trend confirms that the literature base in this field is becoming increasingly abundant and diverse.

Based on bibliometric data analysis from Dimensions.ai, the five most productive authors in research related to seagrass ecosystems and blue carbon conservation are Timothy Rice McClanahan (73 publications), Carlos Manuel Duarte (71 publications), Peter Ian Macreadie (70 publications), Rod M. Connolly (64 publications), and Catherine E. Lovelock (63 publications). These authors are affiliated with leading international marine research centers and universities known for their active contributions to studies on blue carbon, coastal ecosystems, and the impacts of climate change. The dominance of these names suggests that the global knowledge landscape on seagrass and blue carbon is significantly shaped by research networks among scholars from high-science-capacity countries, underscoring the importance of enhancing collaboration and contributions from researchers in tropical regions such as Indonesia. ilmuwan dari negara-negara dengan kapasitas riset tinggi, sehingga mendorong pentingnya kolaborasi dan kontribusi yang lebih besar dari peneliti di wilayah tropis seperti Indonesia untuk menyeimbangkan perspektif global.

In conclusion, the publication trends and leading authors identified from Dimensions.ai data demonstrate a significant rise in global scientific interest in seagrass, its conservation, and sustainable management, in line with the growing urgency of blue carbon and climate resilience issues. The increasing collaboration among researchers and international institutions provides substantial opportunities for developing countries such as Indonesia to actively contribute to global research through academic partnerships and evidence-based policy development.

Results of the SLR Analysis Using the PRISMA Approach

The Systematic Literature Review (SLR) using the PRISMA model is a literature review approach conducted

in a systematic, transparent, and replicable manner to identify, select, assess the quality of, and synthesize research findings relevant to a specific topic. The PRISMA framework (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was developed to standardize the reporting of systematic reviews and meta-analyses through sequential stages of identification, screening, eligibility assessment, and inclusion, which are clearly illustrated in a structured flow diagram. (Moher et al., 2009; Page et al., 2021).

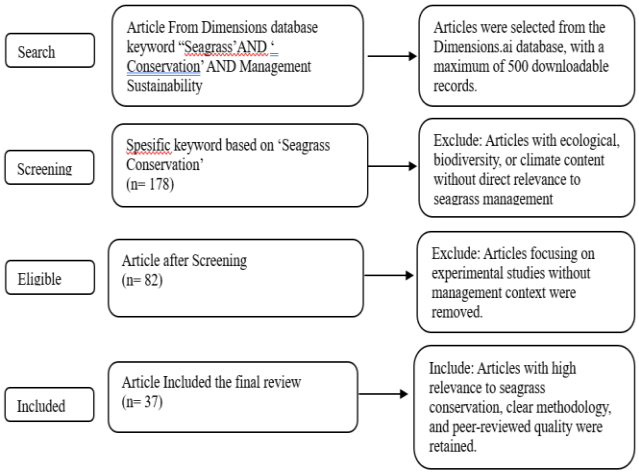

Figure 5. SLR Flow Diagram

At the identification stage, a comprehensive search was conducted across 500 scientific publications obtained from the Dimensions database using the main keywords "seagrass conservation," "management conservation," and "sustainability." This process included articles published between 2000 and 2025, providing a comprehensive overview of the development of seagrass conservation research over time. Most publications were sourced from reputable international journals, including npj Ocean Sustainability, Marine Pollution Bulletin, Ambio, PeerJ, and Frontiers in Marine Science. This stage aimed to ensure that the reviewed literature had broad and representative coverage, thereby offering a holistic understanding of the directions, trends, and contributions of seagrass conservation research worldwide.

The next stage, screening, involved selecting articles relevant to seagrass conservation. In this phase, publications that did not explicitly address conservation, such as those discussing biodiversity, ecology, or climate change without direct linkage to seagrass management, were excluded from further analysis. As a result, 178 relevant articles were retained from the initial 500 identified. This screening step was crucial in ensuring that only literature directly supporting a systematic analysis of seagrass conservation was carried forward to subsequent stages.

At the eligibility stage, a further selection was conducted on articles focusing on management issues, conservation policies, and seagrass restoration activities. Theoretical studies or laboratory-based experiments without managerial implications were excluded. Of these, 82 articles met the eligibility criteria for in-depth analysis. This stage narrowed the scope of the review to literature with practical value for policy-making and the implementation of conservation initiatives in the field. It also ensured that each selected article had a direct and meaningful connection to sustainable seagrass conservation efforts.

The final stage, inclusion, selected articles that met all scientific quality criteria, including peer-reviewed publications with transparent methodologies and strong relevance to seagrass conservation issues. This final selection yielded 37 highly relevant and credible articles for detailed analysis. The thematic synthesis of these 37 studies identified five main categories: Global Ecology and Conservation, Sustainable Management and Policy, Restoration and Blue Carbon, Technology and Monitoring, and National Context (Indonesia). The in-depth analysis revealed that seagrass conservation is increasingly moving toward an integrative and transdisciplinary approach that combines ecological, social, and economic dimensions. Indonesia, particularly the province of West Nusa Tenggara (NTB), serves as a concrete example of how community-based management can effectively strengthen seagrass conservation efforts, enhancing coastal well-being and contributing to climate change mitigation through blue carbon potential.

CONCLUSION

This SLR and bibliometric synthesis confirms that seagrass conservation is a strategic instrument for climate mitigation and coastal ecosystem sustainability, primarily through its blue carbon function. Although research output increased substantially between 2000 and 2025, the evidence base remains spatially uneven, dominated by subtropical regions (e.g., the Mediterranean) with limited representation from tropical systems, including Indonesia.

The literature consolidates into four core themes: biophysical ecology, blue carbon, governance/policy, and socio-economic dimensions, with clear dominance of ecological and carbon-focused studies and comparatively weaker coverage of adaptive governance, policy implementation, and stakeholder engagement. VOSviewer mapping shows strengthening links between the blue carbon and policy–stakeholder clusters, underscoring that durable conservation outcomes depend on integrating ecological evidence with collaborative, evidence-based governance.

For West Nusa Tenggara (NTB), the findings point to high potential for community-based conservation models that couple ecosystem protection with livelihoods and climate adaptation, contingent on strengthened local research capacity, inter-institutional coordination, and enabling policy frameworks that position seagrass as a national climate and coastal development asset.

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