Blue carbon ecosystems in the Coral Triangle: A perceptive approach to climate adaptation

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ABSTRACT

This paper offers a comprehensive synthesis of nine research papers from the Asia-Pacific Network for Global Change Research (APN) project titled "Enhancing Capacities of Local Stakeholders in Coral Triangle in Managing Blue Carbon Ecosystems for Climate Mitigation and Adaptation." These papers are organised into four key thematic areas: (1) assessing the status of mangrove degradation and its underlying factors, (2) exploring community perceptions of seagrass ecosystems and their associated services, (3) analysing local perspectives on sustainable tourism and its influence on blue carbon (BC) ecosystem services, and (4) discerning trends in research and coastal management strategies for BC ecosystems. The findings presented within these papers illuminate the intricate challenges surrounding BC ecosystems in the Philippines and Indonesia, underscoring a range of human-induced pressures and natural vulnerabilities. These studies emphasise the significance of incorporating community perceptions and socio-economic dynamics into the BC ecosystems' conservation and management strategies framework. The comparative insights derived from these papers hold vital implications for local stakeholders and policymakers. Practical training in Geographic Information Systems (GIS) can empower local communities to enhance their capacity-building efforts in the future. This is valuable guidance for shaping future BC ecosystem management plans and programs, particularly in a rapidly changing climate.

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HIGHLIGHTS

- Mangrove degradation, primarily driven by aquaculture expansion, calls for targeted conservation efforts.

- Seagrass ecosystems, often overlooked due to their submerged nature and limited public awareness, demand increased academic and practical attention for their preservation.

- Successful blue carbon initiatives hinge on active engagement with local communities and stakeholders, underscoring the importance of participatory approaches.

- Effective protection and conservation require aligning local regulations with national law enforcement, fostering coordinated efforts toward ecosystem preservation.

- Engaging local communities not only promotes sustainable management but also enhances livelihoods, highlighting the symbiotic relationship between conservation and well-being.

1. INTRODUCTION

Wetlands cover 6% of Earth's surface and hold approximately 12% of the world's carbon (Erwin, 2009). Among wetlands, mangroves play a particularly crucial role in carbon storage in their biomass and within their soils, contributing significantly to global carbon cycling (Zhao et al., 2022). The Ramsar Convention is an intergovernmental treaty that aims to protect, manage, and restore wetland ecosystems, including mangroves, seagrasses, and intertidal marshes. This convention can be strengthened by identifying and designating new Ramsar Sites, improving existing site management, and reducing the threats that lead to coastal wetland degradation and loss (Beers et al., 2020). In line with the objectives of the Paris Agreement established under the United Nations Framework Convention on Climate Change (UNFCCC), the term 'blue carbon' was coined in 2009 within a rapid response assessment report as part of a unique inter-agency collaboration (Alongi, 2018). Notably, the Asia-Pacific Network for Global Change Research (APN) has played a pivotal role in supporting global change research, especially related to climate mitigation, through its funding of collaborative projects across various sectors. APN, in this context, provided funding for the project titled "Enhancing Capacities of Local Stakeholders in Coral Triangle in Managing BC Ecosystems for Climate Mitigation and Adaptation". This project, which has now concluded, adopted a transdisciplinary approach involving communities, practitioners, and scientists, intending to empower local communities and ensure the sustainable use of BC ecosystems, as outlined on the APN website (2021).

This paper serves to summarise all the published papers produced within the framework of the APN-funded project, which has successfully concluded. In general, these publications offer valuable insights into the spatial distribution of existing management strategies and the common challenges faced in managing BC ecosystems across Indonesia and the Philippines. They underscore the importance of bridging science and policy to ensure the conservation and sustainable management of BC ecosystems. Additionally, they highlight how communities perceive BC ecosystem services through their awareness, utilisation, and management activities. This collective knowledge is a pivotal resource for informing future strategies and policy decisions in the era of climate change.

2. THE FOUR GENERAL CATEGORIES OF THE PAPERS ON BC ECOSYSTEMS

The nine papers are divided into the following categories: (1) assessing the status of mangrove degradation and its underlying forces (2 papers); (2) exploring community perceptions of seagrass ecosystems and their associated services (3 papers); (3) analysing local perspective on sustainable tourism and its influence on BC ecosystem services (2 papers), and (4) discerning trends in research and coastal management strategies for the BC ecosystems (2 papers).

2.1. Assessing the status of mangrove degradation and its underlying forces

Two papers in this section analysed the perceptions of local coastal communities and their involvement in mangrove management. They also studied the driving forces behind mangrove forests and the degradation of their BC stock in the Philippines and Indonesia. Quevedo et al. (2022a) presented the importance of mangrove ecosystems in Eastern Samar province, Philippines, for bridging terrestrial and marine ecosystems, providing ecosystem services and sequestering carbon. It has provided valuable insights into the dynamics of mangrove cover change (MCC) and emphasised the importance of considering local community perceptions and socio-economic factors in mangrove conservation. This study investigated MCC dynamics in the study area, utilising primary and secondary data. Primary data collection involved household surveys conducted in three coastal villages. These surveys gathered information on respondents' perceptions of MCC, including observed changes, drivers, and timelines. The survey also asked respondents to rank the importance of various drivers of MCC. Multiple sources were employed to collect secondary data, including population density, typhoon track archives, remote sensing data on mangrove cover, mangrove-related policies, and mangrove awareness. These sources were used to complement and validate the primary data. The results revealed that the mangrove cover in the study sites had generally declined over time. The community perceptions collected aligned with observed changes in mangrove cover, as indicated by remotely sensed data. The overall trend showed a decrease in mangrove cover from approximately 752 hectares in 1990 to around 558 hectares in 2016, followed by a gradual increase to about 630 hectares in 2019. Anthropogenic drivers attributed to human activities, such as converting mangrove areas to fishponds, were identified as significant drivers of MCC, especially in the earlier periods (1960s to early 2000s). Underlying factors like poverty and weak policy implementation influenced these activities.

Moreover, natural threats such as typhoons were also recognised as contributors to mangrove loss, with Typhoon Haiyan in 2013 having a particularly significant impact (Quevedo et al., 2020a). The perceived effects of recent typhoons were more potent than those of older ones, possibly due to individual experiences and the increasing intensity of recent typhoons linked to climate change. In addition to typhoons, rising sea levels significantly threaten coastal ecosystems. Their physical effects include the inundation of low-lying wetlands and drylands and an increased risk of flooding (Perez et al., 1999). The Philippines is particularly susceptible to sea level rise and extreme rainfall, which severely affect human life, infrastructure, agriculture, and natural ecosystems (Hong et al., 2022). Similarly, coastal areas in Jakarta are experiencing severe land subsidence, further exacerbating the threats posed by rising sea levels and increasing risks for local communities (Esteban et al., 2017).

Furthermore, addressing these challenges requires urgent and strategic action, with mangrove reforestation playing a vital role in mitigating climate change, protecting coastlines from high tidal waves, and reducing flood risks (Alsaaideh et al., 2013). The study also examined how socio-demographic attributes and awareness of mangrove ecosystem services influenced the recognition of MCC drivers. This research emphasises that understanding local perceptions of MCC and its drivers provides valuable insights for developing sustainable mangrove management strategies. Science-based approaches to mangrove reforestation can enhance resilience against natural threats, while community perceptions can complement traditional data sources in the analysis of MCC.

Using the Driver-Pressure-State-Impact-Response (DPSIR) framework as a holistic tool for identifying and establishing causal links between various indicators in environmental management (Kohsaka, 2010). Quevedo et al. (2023a) applied the framework to identify both the threats and management efforts related to mangrove ecosystems across all 27 provinces of Indonesia. The methodology involved data collection from Scopus and Web of Science databases and included a screening process to select relevant peer-reviewed articles. The se-

lected articles are then analysed using the DPSIR framework to identify drivers, pressures, impacts, and responses to mangrove ecosystems. The results exposed that Central Java has the highest number of publications related to mangroves, followed by East Kalimantan and South Sulawesi. In contrast, some provinces have very few or no articles on the topic of mangroves. The analysis also displayed increased articles discussing mangrove degradation and management in recent years.

Furthermore, this study provided an overview of Indonesia's regional and provincial trends in mangrove degradation and management efforts. With its high population density, the Java region experiences indirect anthropogenic drivers, like population growth, leading to societal pressures on mangroves. Aquaculture expansion is a prominent driver in Kalimantan, resulting in mangrove loss. Papua province enforces stricter mangrove management due to large-scale oil palm plantation development, while the Maluku islands face societal and institutional pressures and indirect anthropogenic forces. Sulawesi has witnessed significant mangrove conversion for aquaculture, while Sumatra deals with issues like oil palm plantation development and the impact of aquaculture on mangroves. Natural drivers, such as earthquakes and tsunamis, are documented in provinces that experience vigorous seismic activity, and climate change, particularly sea level rise, affects mangroves and coastal communities in Jakarta and Central Java. The study suggested that the future of Indonesia's mangroves depends on achieving a balance between economic development and sustainability. Essential measures include policies that promote sustainable aquaculture and mangrove conservation and the implementation of payment for ecosystem services and financial valuation, particularly within BC. Moreover, it is recommended to foster collaboration with stakeholders, including non-governmental organisations (NGOs), and to incorporate eco-tourism concepts.

Building on these findings, a systematic assessment using the DPSIR framework can further highlight the vulnerabilities of Indonesia's mangrove ecosystems and guide sustainable management strategies. Drivers such as population growth, urbanisation, industrial expansion, weak policy enforcement, climate change, and seismic activity contribute to increasing pressures. These pressures manifest as aquaculture expansion, oil palm plantations, deforestation, pollution, and coastal infrastructure development, leading to widespread mangrove degradation. As a result, the state of mangroves has been significantly affected, with shrinking forest cover, declining biodiversity, and reduced carbon sequestration capacity, making these ecosystems increasingly fragile. The impacts of these changes include coastal erosion, increased flooding, declining fishery productivity, higher carbon emissions, and socioeconomic displacement of coastal communities.

Despite ongoing conservation efforts, such as mangrove reforestation programs, national policy frameworks, and community-based restoration initiatives, gaps remain in law enforcement, sustainable land-use planning, and long-term community engagement. Addressing these vulnerabilities requires strengthening legal frameworks, promoting sustainable aquaculture, integrating local ecological knowledge into conservation strategies, and embedding mangrove conservation into disaster risk reduction plans. A balanced approach reconciling economic development with environmental sustainability is essential to protecting Indonesia's mangroves from intensifying human pressures and climate-related threats.

2.2. Exploring community perceptions of seagrass ecosystems and their associated services

In this section, three papers discuss the significance of seagrass ecosystems and their role in providing various ecosystem services.

Quevedo et al. (2022b) compared local perceptions of rural and urban areas through household surveys to understand how different contexts influence people's awareness and attitudes toward seagrass ecosystems in the Philippines. The study provided insights into seagrass conservation at a local scale, where specific conservation and management strategies are needed. Overall, respondents in rural areas displayed higher awareness and utilisation of seagrass ecosystem services and had a stronger connection to these services than those in urban areas. For instance, significant differences were observed in awareness levels of services like nurseries, the frequency of seagrass bed utilisation as an income source, and awareness of coastal management-related strategies, which were significantly higher in rural areas than in urban areas. This difference in perception can be attributed to the direct experience of rural communities with natural events like typhoons, during which seagrass meadows have been observed to provide protection. Urban

respondents were more concerned about pollution from domestic waste and were aware of seagrass meadows as recreational sites, possibly due to their proximity to tourist destinations. The findings of this paper highlighted that the concept of seagrass BC is poorly understood and not mainstreamed in local coastal management plans (Quevedo et al., 2020b).

The study emphasised the need to increase awareness of BC among local stakeholders, especially those who rely on seagrass habitats for their livelihoods. It also highlighted the importance of community engagement in seagrass conservation efforts and the potential for citizen science initiatives. Partnerships between residents, practitioners, and policymakers could lead to context-based seagrass management plans and programs in rural and urban settings.

Rifai et al. (2023a) analysed community perceptions of seagrass ecosystem services in Indonesia's Karimunjawa National Park (KNP), a protected area with various seagrass species. The research aimed to provide insights and recommendations for improving seagrass ecosystem management from a social perspective. Data were collected through household interviews in three coastal villages within KNP, and respondents were selected randomly to represent various demographic groups. The respondents displayed high awareness of some seagrass ecosystem services, such as their role as nurseries for marine organisms and in water purification. However, awareness of other services, such as carbon sequestration and coastal protection, was relatively low. Moreover, respondents had misconceptions regarding the carbon storage capacity of seagrass ecosystems. A significant proportion believed that most of the carbon was stored in seagrass biomass, while, in fact, most of the carbon was held in the sediment. The results indicated that higher education is associated with greater awareness levels.

Therefore, the study underscores the importance of enhancing community awareness regarding seagrass ecosystem services, particularly carbon sequestration, and the necessity for customised conservation and education efforts. Additionally, it highlights the role of community perceptions in shaping conservation strategies and the potential for Payment of Ecosystem Services (PES) schemes to bolster seagrass conservation in Indonesia's Komodo National Park.

Rifai et al. (2023b) introduced the concept of seagrass restoration as a nature-based solution (NbS) to address climate change and promote ecosystem health. NbS is actions that protect, manage, and restore natural ecosystems to benefit human well-being and biodiversity. Seagrass restoration aligns with NbS principles, and the paper provided evidence of how seagrass restoration fits the criteria set by the International Union for Conservation of Nature (IUCN) for NbS. This study highlighted the potential for implementing seagrass restoration as a NbS in Indonesia, particularly in addressing climate change mitigation and adaptation. The paper acknowledged challenges, such as the lack of a national budget and low community awareness about seagrass restoration. The study underscored the need for collaboration among stakeholders, including the scientific community, government, local communities, and NGOs, to address these issues. Capacity building, awareness campaigns, realistic restoration designs, and payment for ecosystem services are proposed as potential solutions. The paper advocates for recognising seagrass restoration as a valuable tool in Indonesia's efforts to combat climate change. It encourages more attention, funding, and collaboration to restore and protect these critical marine ecosystems.

While community awareness is crucial in shaping conservation strategies, translating this awareness into concrete actions is essential for ensuring the health and sustainability of seagrass ecosystems. Building on Rifai et al.'s (2023a, 2023b) findings, addressing knowledge gaps, particularly regarding seagrass carbon sequestration is paramount. To complement these insights, effective monitoring and restoration efforts are vital for maintaining ecosystem services and promoting long-term sustainability.

Community awareness efforts should particularly emphasise the significance of monitoring and restoration as key strategies in seagrass conservation. Regular monitoring is crucial in assessing ecosystem health, identifying early signs of degradation, and informing adaptive management strategies to sustain seagrass ecosystems over time. Involving local communities in seagrass monitoring through citizen science initiatives collects valuable data, fosters a sense of ownership, and enables timely responses to emerging threats. Furthermore, restoration activities, such as replanting seagrass beds and mitigating human-induced damage, should be prioritised at the grassroots level to re-

store ecosystem services and ensure the long-term viability of seagrass habitats.

A comprehensive and inclusive approach to seagrass monitoring and restoration can lead to more effective and sustainable conservation outcomes. Communities should be equipped with the necessary tools and knowledge to monitor programmes and track changes in ecosystem health actively. Citizen science initiatives, where local residents contribute to data collection and restoration efforts, can further foster a sense of stewardship and long-term commitment to seagrass conservation. To strengthen these efforts, prioritising education, collaboration, and financial incentives is crucial for enhancing ecosystem conservation and contributing to climate change mitigation on a global scale. Recognising seagrass restoration as a vital NbS will help drive policy changes, secure funding, and reinforce community-led conservation initiatives. Finally, integrating traditional ecological knowledge with scientific research can empower coastal communities to protect and restore these critical marine ecosystems for future generations.

2.3. Analysing local perspective on sustainable tourism and its influence on BC ecosystem services

The tourism expansion has brought significant economic advantages to the public and private sectors, particularly in coastal regions. However, its rapid growth has also led to environmental degradation, including the loss of seagrass and mangroves due to coastal developments, pollution, and increased human activity (Daby, 2003; Spalding & Parrett, 2019). Understanding the interactions between tourism and these habitats is essential, as mangroves and seagrasses are vital blue carbon ecosystems contributing to climate mitigation. Unlike other sectors, tourism relies on and impacts these ecosystems, making it a crucial area for developing sustainable management strategies that balance economic growth with conservation.

This section contains two papers on the impacts of tourism, mainly on mangroves and seagrass.

Quevedo et al. (2021a) provided valuable insights into residents' perceptions of tourism benefits and impacts in rural and urban settings in the northern part of Palawan province, Philippines, with a focus on the importance of BC ecosystem services, including mangroves and seagrass beds. The study conducted household surveys in coastal villages and covered various aspects, including awareness of BC ecosystem services, perceived benefits, tourism impacts, environmental changes, and sustainable tourism measures. Participants rated their awareness of the benefits of mangroves and seagrass and their opinions on sustainable tourism measures using a Likert scale. The study also explored residents' perceptions of the impact of tourism on their personal and community well-being, encompassing social, cultural, economic, and environmental dimensions. Additionally, it examined changes in habitat cover, conservation efforts, accessibility, and seafood stocks related to mangroves and seagrasses. The study found that respondents in both areas recognised the importance of protecting natural resources for the sustainability of the tourism industry. For example, residents in both areas demonstrated a high awareness of the benefits of mangroves, such as coastal protection. In rural areas, the functions of seagrass ecosystems were recognised more, possibly due to awareness campaigns conducted by NGOs in the area. On the other hand, residents generally have positive perceptions of the economic benefits of tourism, such as its potential to generate income and employment opportunities. However, there was also recognition that tourism could lead to rising prices of goods and services and increased competition for local jobs, which could have adverse effects. Overall, this research provided a valuable foundation for local governments to develop policies and strategies for sustainable tourism. These should balance economic development with environmental protection and the well-being of residents. The study highlighted the importance of community awareness and engagement in achieving these goals and underscores the role of NGOs in facilitating this process.

To assess the residents' perceptions of the impact of tourism on coastal ecosystems in Karimunjawa, Indonesia, Lukman et al. (2022) involved 47 respondents and employed a questionnaire-based survey that focused on sustainability dimensions: socio-cultural, economic, and environmental. Chi-square tests were used to evaluate associations between residents' perceptions, the prioritisation of coastal management, and their involvement in the tourism sector. The results indicated that respondents had a positive perception of tourism's socio-cultural and economic impacts and negative perceptions regarding its impact on the environmental domain, especially among those involved in the tourism sector. Education level was negatively correlated with environmental per-

ceptions, indicating that higher education levels led to more negative perceptions. The study emphasises the need for comprehensive coastal ecosystem management, involving the local community and addressing environmental concerns while also recognising the economic benefits of tourism. Further research was recommended to delve into the intricacies of these perceptions and involve various stakeholders in policy discussions.

2.4. Discerning trends in research and coastal management strategies for BC ecosystems

Two papers in this section provide information on the status and challenges of published research and the management strategy concerning the BC ecosystem.

Quevedo et al. (2023b) identified that since the concept of BC was introduced in 2009, there has been substantial research progress in various aspects, such as BC quantification, mapping, economic opportunities, and management. However, the paper emphasises that several challenges remain, as indicated by ten fundamental questions in BC science, mainly focusing on the question related to management actions for BC sequestration. To address these challenges, the study conducted a comprehensive literature review, which included peer-reviewed articles, technical reports, policy briefs, books, conference presentations, dissertations, theses, and news articles. This approach aimed to provide a more comprehensive perspective on BC research, including earlier developments and contributions from civil society that may have been overlooked in previous reviews. To support scholars in shaping their research agendas, avoiding redundancies, and assisting coastal managers and practitioners in developing evidence-based BC management strategies, the authors collected BC-related documents from various databases, such as Scopus, Web of Science, and others. They retrieved 4,206 potential documents and conducted a rigorous screening process to narrow the selection to 1,179 relevant documents. The study revealed that the number of BC-related documents has increased from 2009 to 2021, with peer-reviewed articles dominating the literature. The analysis of co-occurrence networks showed that BC research is multidisciplinary, covering both natural and social sciences. The geographic distribution of BC research is led by the United States and Australia, with a robust co-authorship network. While Asia, particularly China, has shown a significant research output, collaborations with other countries are still limited, especially among developing countries.

The paper highlighted the growing importance of social and management perspectives in BC research and points out the continued growth and significance of BC research. It also presented a roadmap for future research agendas to advance the field. By addressing these research agendas, BC science can continue to evolve, become more inclusive, and contribute to more effective coastal management and policy development.

Quevedo et al. (2021b) examined coastal management plans in selected municipalities in the Philippines, focusing on mangrove and seagrass ecosystems. The study employed content analysis to assess the management plans and discussed the clusters derived from the analysis. Eight groups were identified: environmental profiles, ecosystem services, carbon sequestration, tourism, natural and anthropogenic threats, laws and policies, and management activities. The analysis revealed that management activities received the most attention, while carbon sequestration received the least. It is worth noting that the concept of BC has not been fully integrated into these plans, and management strategies primarily concentrated on mangrove forests, with limited attention given to seagrass meadows. The emphasis on mangrove forests is due to their coastal protection services, which became particularly evident after the super typhoon Haiyan in 2013. The lack of attention to seagrass ecosystems suggests a need for increased research and collaboration with mangrove conservation efforts. The results demonstrated that the coastal management plans do not account for indirect drivers such as urbanisation, which can impact mangrove and seagrass ecosystem losses. Most discussions focused on direct drivers like human-induced disturbances and natural events. Future investigations could involve in-depth interviews with local government units and the application of frameworks to understand these drivers better. This study can serve as a reference for local policymakers to improve their management plans, especially by focusing on the integrated management of seagrass ecosystems and enhancing knowledge about BC ecosystems.

3. PROMISING FUTURE CAPACITY-BUILDING APPROACH: A CONCEPTUAL FRAMEWORK FOR COMMUNITY ADAPTATION

This review addresses a critical research gap: How do capacity-building programmes enhance

local communities' adaptation capacity in managing mangrove and seagrass ecosystems in Indonesia and the Philippines? While previous studies highlight the role of local communities in conservation, there is limited understanding of the impact and limitations of such programmes in fostering long-term resilience. Specifically, this review investigates how Geographic Information Systems (GIS)-based training can empower local communities to overcome governance and implementation challenges in blue carbon ecosystem management.

3.1. Conceptual framework: Behaviour change and community adaptation

We draw from environmental psychology and climate adaptation frameworks to guide this discussion. The Theory of Planned Behaviour (TPB) (Whitmarsh et al., 2021) posits that attitudes, perceived control, and social norms influence individuals' actions. Applying this to community-based conservation, effective adaptation strategies require technical training and behavioural shifts that enhance local agency, promote collective responsibility, and ensure that communities view conservation efforts as valuable and achievable.

Furthermore, we propose a Theory of Change (ToC) framework (Deutsch et al., 2021) to illustrate how GIS training can improve adaptation capacity:

1. Knowledge and skill development: Training local communities in GIS equips them with the technical skills to map, assess, and monitor mangrove and seagrass ecosystems.
2. Participatory data collection and perception integration: Incorporating local knowledge into GIS databases ensures that conservation strategies reflect on-the-ground realities.
3. Data-driven decision-making: Reliable spatial data enables local stakeholders and policymakers to make evidence-based conservation and adaptation decisions.
4. Improved governance and community Empowerment: GIS training fosters collaboration between communities, researchers, NGOs, and government agencies, strengthening institutional capacity.
5. Long-term sustainability and adaptation capacity: With enhanced monitoring and governance structures, communities can anticipate environmental changes, assess climate risks, and implement sustainable conservation measures.

3.2. Policy barriers and supportive policy frameworks

National policies that either support or hinder conservation efforts heavily influence the effectiveness of GIS-based capacity-building programs. Policy barriers such as weak enforcement of environmental regulations, fragmented land-use planning, and a lack of integration of blue carbon into national climate strategies can undermine these initiatives. Furthermore, policies prioritising economic growth (e.g., unsustainable coastal development or agriculture) without considering ecological impacts may exacerbate pressures on mangrove and seagrass ecosystems.

In contrast, supportive policies that integrate blue carbon conservation into broader climate change adaptation and mitigation strategies can significantly enhance the success of these programs. National policies should promote sustainable land-use practices, empower local communities, and ensure that conservation strategies are evidence-based and collaborative. Strengthening policy integration and ensuring long-term financial and institutional support for capacity-building programs are critical for realising the full potential of GIS-based training in blue carbon ecosystem management.

3.3. Implications for capacity-building programs

GIS-based training programs offer a promising approach, bridging the gap between local knowledge and policy implementation. By enabling communities to track ecological changes, assess vulnerabilities, and contribute to data-driven governance, such programs enhance local agencies in climate adaptation. However, the effectiveness of these programs depends on long-term engagement, institutional support, and accessibility of resources.

Future research should evaluate the impacts of GIS training on decision-making and ecosystem resilience, as well as potential barriers such as resource constraints, policy integration challenges, and community engagement sustainability. Addressing these gaps will ensure that capacity-building programs bring tangible, lasting improvements in adaptation and conservation efforts.

4. CONCLUSION

This study highlights coastal communities' perceptions of blue carbon ecosystem services, emphasising their awareness of management policies, utilisation of ecosystem resources, and participation in conservation initiatives. The findings reveal that

indirect anthropogenic drivers, such as population growth and economic development, exert significant pressure on BC ecosystems, particularly mangroves and seagrasses, crucial for climate change mitigation. Additionally, the study underscores the need for increased community awareness and engagement in conservation efforts, particularly concerning the carbon sequestration potential of seagrass ecosystems.

Building on these insights, the study presents a conceptual framework incorporating Geographic Information Systems (GIS) based training as a strategic tool to enhance community adaptation and governance in blue carbon ecosystem management. By equipping local communities with technical skills in spatial analysis, GIS training facilitates participatory data collection, supports evidence-based decision-making, and promotes stronger institutional collaboration. Applying behavioural change models, such as the Theory of Planned Behaviour (TPB), emphasises the necessity of fostering local agency, encouraging collective responsibility, and ensuring conservation efforts are considered valuable and attainable. The Theory of Change (ToC) framework further demonstrates how structured capacity-building programmes can drive long-term sustainability by improving governance, enabling adaptive management, and empowering communities to respond effectively to environmental changes.

Despite the promising potential of GIS-based capacity-building programmes, their success is contingent upon the broader policy landscape. Supportive policies can enhance these efforts, while several barriers exist such as fragmented policies, weak governance, and unsustainable development practices. Integrating blue carbon ecosystems into national climate change policies, promoting sustainable coastal development, and strengthening the enforcement of environmental regulations are critical steps to ensuring the long-term sustainability of these ecosystems. The effectiveness of capacity-building programmes also depends on institutional support and policy integration. Future research should focus on evaluating the long-term impacts of GIS-based training on decision-making, the resilience of BC ecosystems, and addressing policy-related barriers such as resource limitations and policy gaps. Strengthening these areas will ensure local communities actively contribute to blue carbon conservation, ultimately leading to more sustainable and climate-resilient ecosystem management strategies.

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