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Introduction of Blue Carbon Management

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ABSTRACT

Climate change presents one of the most pressing global challenges, impacting diverse life forms across the planet. As anthropogenic greenhouse gas emissions continue to rise, it becomes increasingly urgent to explore effective strategies to mitigate climate change's adverse effects. Among these strategies, carbon sequestration plays a crucial role, particularly in coastal and marine ecosystems that can capture and store substantial amounts of carbon. Carbon sequestration encompasses three primary categories: carbon capture and storage (CCS), carbon capture and utilization (CCU), and carbon dioxide removal (CDR). The range of CDR includes technological and natural methods. In this study, we mainly focus on natural strategies, which address environmental challenges and promote sustainable development under the term "nature-based solutions," wherein the concept of "blue carbon" is situated. Blue carbon specifically refers to coastal and marine ecosystems, particularly mangroves, salt marshes, and seagrasses. The study and management of blue carbon ecosystems are imperative due to their exceptional capacity to sequester carbon dioxide, thereby offering a substantial means to mitigate climate change. Understanding and effectively stewarding these ecosystems hold the potential to not only curtail greenhouse gas concentrations, but also preserve biodiversity, bolster coastal resilience, and foster sustainable development. This study proposes a conceptual framework to encourage the development of schemes focused on managing blue carbon sequestration in order to mitigate climate change. This process takes into consideration various measures, including environmental education, research and technology, economy, law and regulation, and regional and international cooperation.

Keywords: Carbon sequestration, climate change, carbon adaptation.

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1 INTRODUCTION

In an era defined by the unrelenting challenges of global climate change, the imperative to seek and implement innovative solutions has assumed unprecedented urgency. The world finds itself at a critical juncture where the consequences of human activities, particularly the unabated release of greenhouse gasses into the atmosphere, have precipitated far-reaching climatic shifts (Denchak, 2023). As a result, the pressing need to mitigate these impacts has galvanized international efforts across myriad sectors. Among these endeavors, carbon sequestration has emerged as a cornerstone strategy in the battle against climate change (Brogan, 2022).

Carbon sequestration, encompassing various mechanisms that facilitate the capture and long-term storage of carbon dioxide (CO_2), constitutes an essential component of the multifaceted approach to combat escalating global temperatures (Tcvetkov et al., 2019). An essential subset of this approach is the management of blue carbon ecosystems, including coastal habitats such as mangroves, seagrasses, and tidal marshes (Nellemann et al., 2009). The intricate interplay between these ecosystems and their unparalleled capacity to sequester carbon, often referred to as "blue carbon," renders them integral in the broader tapestry of climate mitigation strategies (Beaumont et al., 2014).

This study delves into the fundamental realm of carbon sequestration and blue carbon management, examining their potential and proposing an efficient management plan to reshape the trajectory of climate change mitigation. Through a comprehensive exploration of the underpinnings of carbon sequestration and the strategic management of blue carbon ecosystems, this study aims to underscore the transformative role of these approaches in curbing the adverse consequences of climate change.

2 CARBON SEQUESTRATION

The process by which CO_2 is captured from the atmosphere and stored, usually in natural ecosystems or engineered systems, is known as carbon sequestration (Alongi, 2012). This helps to mitigate the effects of excess CO_2 in the atmosphere, which contributes to global warming. Carbon sequestration is crucial for combating climate change, and in order to effectively address this issue, it is vital to differentiate between the various functions that carbon management options can or cannot fulfill in mitigating climate change. This differentiation will provide insights to select the most suitable approach for specific situations. The organization of these methods could be divided into: carbon capture and storage (CCS), carbon capture and utilization (CCU) (Tcvetkov et al., 2019), and carbon dioxide removal (CDR) (Figure 1).

Carbon capture and storage (CCS) is a process in which a relatively pure stream of CO_2 from industrial and energy-related sources is separated (captured), conditioned, compressed, and transported to a storage location for long-term isolation from the atmosphere. Sometimes referred to as carbon capture and storage (IPCC, 2023), carbon capture and utilization (CCU) or carbon capture, utilization, and sequestration (CCUS) is part of a broader set of "carbon recycling" applications, describing the reuse of captured carbon either directly (e.g., to fertilize plants or to be added in beverages) or as an ingredient in new products (e.g., concrete, fuels, chemicals). CCU can displace additional fossil fuel use, thereby reducing emissions. If the carbon is removed from the atmosphere and stays in a closed loop over many decades or centuries (e.g., when incorporated into cementitious building materials), the method may be considered removal. All other cases of CCU, in which carbon is rapidly (re-)released to the atmosphere, only delay (re-)emissions. As most captured carbon is not durably stored, CCU is generally not considered removal (IPCC, 2023; Carbon Gap, 2022).

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Carbon dioxide removal (CDR) refers to anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical CO_2 sinks and direct air carbon dioxide capture and storage (IPCC, 2023). A range of CDR strategies, using both natural and technological methods, aim at extracting CO_2 from the atmosphere and subsequently storing it utilizing diverse mechanisms (Keller et al., 2018). These mechanisms encompass, among others, the sequestration of carbon within trees and vegetation, integration into soils, confinement within subterranean repositories, interaction with minerals, incorporation into the ocean, and integration into materials like concrete (Samaniego et al., 2023). It is imperative to recognize that each approach to carbon removal is accompanied by distinct sets of risks and associated benefits.

The approach of CDR includes technological and natural methods (Figure 1). In terms of anthropogenic technology, sophisticated processes like direct air capture, involving specialized apparatuses to directly retrieve CO_2 from the atmosphere, and advanced mineralization, harnessing specific mineral reactions for carbon sequestration, come into play (Harvey, 2023). On natural methods lies a subset of strategies known as nature-based solutions (NbS), such as reforestation and the particular management of agricultural soils, where organic materials foster carbon storage (Dellesky, 2023).

Embracing NbS for carbon removal emerges as a strategic choice, capitalizing on the demonstrated efficacy of natural ecosystems in carbon sequestration. These methods not only adeptly capture carbon, but also yield a range of ancillary benefits, encompassing biodiversity enrichment, ecosystem services, cultural significance, and noteworthy cost-effectiveness (Samaniego et al., 2023). Besides, NbS exhibit a lesser degree of risk compared to some technology-driven approaches. This inherent safety stems from the fact that these solutions leverage existing ecosystems, requiring minimal human intervention beyond the preservation of efficient ecological processes (Herrmann-Pillath et al., 2022). Unlike certain high-tech strategies, NbS harness the innate capabilities of ecosystems to perform tasks they naturally excel at. This inherent suitability extends universally, rendering them viable for implementation across diverse countries and regions. Moreover, their appeal is magnified by their cost-effectiveness, demanding less investment and fewer resources than some alternative strategies (Wellmann et al., 2023).

In contrast, methods like CCS or CCU, while touted as solutions, often fall short in reducing atmospheric CO_2 levels. These technologies might absorb carbon, but their effectiveness in genuinely curbing CO_2 emissions remains questionable (Carbon Gap, 2022). Not to mention the cost they demand and risks they might have. Therefore, the allure of NbS lies not only in their efficiency, minor budget, and low risk profile, but also in their capacity to provide a sustainable and impactful means of addressing the global climate challenge (De Jesús Arce-Mojica et al., 2019). NbS synergistically integrate ecological benefits with carbon removal efforts, contributing to a holistic approach for mitigating climate change. These solutions aim to work in harmony with nature, harnessing its integral resilience and services to achieve positive outcomes for both the environment and human well-being (Ashford et al., 2023).

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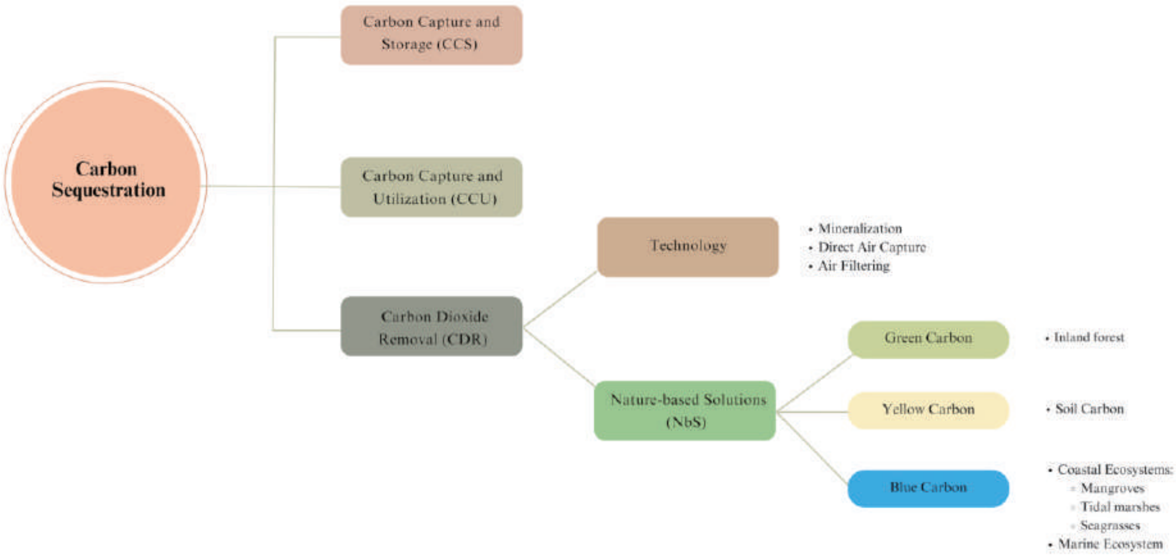

Figure 1. Carbon Sequestration Scheme.

These solutions leverage the inherent capacity of ecosystems to sequester carbon and enhance overall environmental resilience (Martin-Roberts et al., 2021). Reforestation initiatives, for instance, involve the deliberate planting of trees in deforested areas, harnessing the natural carbon absorption capabilities of forests, which is what we know today as "green carbon" (Mackey et al., 2008). Similarly, NbS not only bolster crop productivity, but also facilitate the sequestration of carbon within the soil matrix, most known as "yellow carbon" (Ontl & Schulte, 2012). In addition, coastal and marine ecosystems, including mangroves, salt marshes, and seagrasses, have an exceptional capacity to sequester and retain CO_2 from the atmosphere and ocean, making them valuable "blue" carbon sinks (Nellemann et al., 2009), also known as "blue carbon." The above represent distinct facets of nature's capacity to mitigate climate change and foster ecological resilience. For this study, our focus shall be directed towards the subject of blue carbon.

3 BLUE CARBON MANAGEMENT

"Blue Carbon Enhancement" refers to activities or strategies aimed at increasing the capacity of coastal and marine ecosystems to capture and store CO_2 from the atmosphere. These ecosystems naturally sequester significant amounts of carbon, and enhancing their capacity to do so can have positive implications for climate change mitigation and ecosystem health.

To fully capitalize on and enhance the existing blue carbon potential, an efficient blue carbon management approach becomes paramount. Conservation, restoration, and sustainable use of these ecosystems are fundamental components of blue carbon management, ensuring their resilience and ability to maximize carbon sequestration and storage (Beaumont et al., 2014). By employing sound management practices, we can enhance the capacity of these habitats to capture and retain significant amounts of CO_2 from the atmosphere, bolstering their role in mitigating climate change (Fennessy & Beers, 2023). The synergy between blue carbon sequestration and management not only reinforces the ecological importance of coastal and marine ecosystems but also underscores their indispensable contribution to global climate resilience and sustainability (Bandh et al., 2023).

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The growing attention of different actors, from academia to regulatory bodies, towards blue carbon highlights the need for improved methodologies to accurately measure carbon sequestration (Macreadie et al., 2019). Through effective integration of both ecological and social perspectives, we can foster the development of robust and enduring management frameworks that effectively mitigate the socio-economic costs and ecological impacts of a changing climate (Bryan et al., 2020).

Therefore, investigation and evaluation are the initial steps towards a well-founded management plan focused on conservation, restoration, and sustainable use of our ecosystems (Levin et al., 2009), as well as a series of actions, which are discussed later in this document, that we believe could create a conceptual framework of blue carbon management (Figure 2).

Prior to initiating any conservation, restoration or sustainable use, conducting research and evaluation of the area is imperative to establish the necessary groundwork and determine the appropriate course of action, based on the specific focus of the project (Karstens et al., 2019). By leading comprehensive research and evaluation, we gain essential insights into the area's ecological characteristics, biodiversity, and potential threats (Baker et al., 2013). This knowledge informs the development of tailored conservation, restoration or sustainable use strategies, ensuring that the chosen approach aligns effectively with the unique requirements of the ecosystem.

A pivotal role in the realms of conservation, restoration, and sustainable use is policy formulation, since effective policies serve as the foundation upon which actions are taken to address critical issues (Dudley et al., 2018). These policies define the legal, regulatory, and strategic framework within which various stakeholders, including governmental bodies, research institutions, NGOs, and industries, collaborate to achieve common environmental objectives, for which communication between them is key (Borrini-Feyerabend et al., 2021). In this context, science-based policies and laws are vital. These policies rely on rigorous scientific research to inform decision-making, ensuring that actions taken are grounded in accurate and up-to-date information. By considering the complex interplay of ecological processes, science-based policies offer a holistic perspective that minimizes unintended consequences and supports long-term sustainability (Edler et al., 2022). These policies enhance credibility, trust, and legitimacy among stakeholders, fostering cooperation and smoother implementation.

Regardless of whether the objective is conservation, restoration or sustainable use, a well-informed decision-making process, driven by thorough research and evaluation, is fundamental to the successful implementation of measures and actions that will safeguard and enhance the ecosystem's health and resilience (Rehbein et al, 2020).

Following the determination of the most appropriate approach among conservation, restoration, or sustainable use, the engagement of stakeholders becomes essential for collaborative decision-making, fostering a collective understanding of intricate scientific insights (Colvin et al., 2016). This transparent interaction ensures inclusivity, enabling a diverse range of stakeholders—from governmental entities to local communities—to actively contribute to meticulously tailored policies that align environmental priorities with socio-economic considerations. Moreover, effective communication serves as a bridge linking rigorous scientific research and the formulation of evidence-based strategies (Atalla et al., 2022). This exchange of information not only enhances public awareness, but also garners support and encourages the adoption of sustainable behaviors. Continuous dialogue further facilitates adaptive management, resolves conflicts, and monitors progress, cultivating a holistic paradigm that seamlessly interweaves technical acumen with the nuanced interplay of human and environmental factors inherent in marine policy (Langlet & Rayfuse, 2019).

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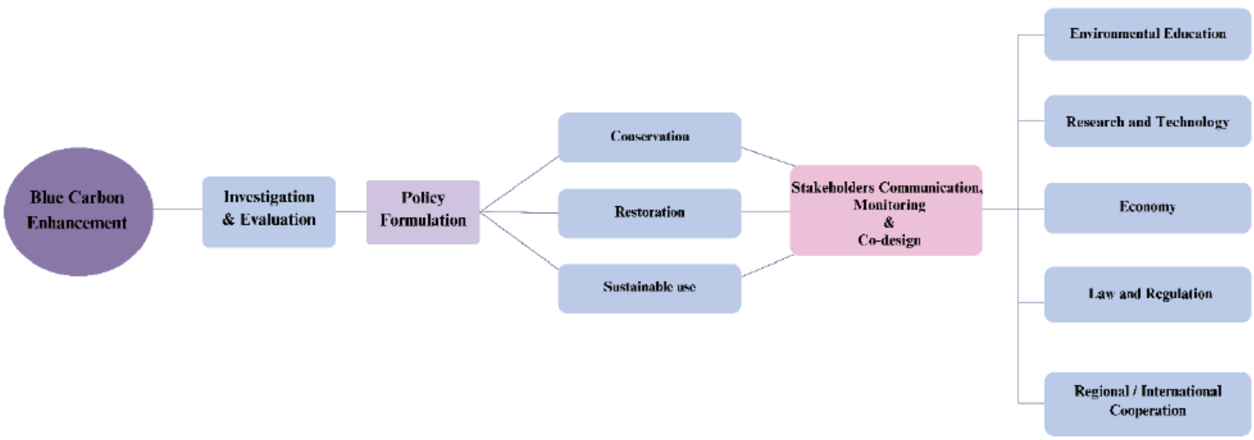

Figure 2. Conceptual Framework of Blue Carbon Management.

4 MANAGEMENT MEASURES

- Engagement of communities in policy making

It is vital to consider the engagement of communities in policy making, especially in the realm of marine environment and climate change. By doing so, we can harness local knowledge, foster ownership, and ensure that policies respect cultural and social aspects. This also enhances compliance, encourages innovation, and promotes social equity. Involving communities leads to more sustainable, resilient, and effective policies that consider the needs and aspirations of those most directly affected (Aguilar et al., 2015).

- Technology-based spatial planning and monitoring for blue carbon

Coastal communities often possess invaluable local knowledge that can be integrated with advanced technology to inform spatial planning. Their insights into marine ecosystems, combined with technologies, such as remote sensing and Geographic Information Systems (GIS), create comprehensive data for effective decision-making (Sullivan et. al., 2015). By combining these technologies with scientific data, policymakers and conservationists can map and analyze the distribution of blue carbon-rich habitats, like mangroves and seagrasses, with high precision. This information is essential for effective spatial planning, helping to identify areas for conservation, restoration, or sustainable use (Carlson et. al., 2021). Additionally, real-time monitoring through technology makes the continuous assessment of blue carbon stocks and emissions possible, aiding in climate change mitigation efforts. Furthermore, this approach can engage local communities in data collection and interpretation, fostering a sense of ownership and promoting the sustainable management of these critical ecosystems. In summary, technology-based spatial planning and monitoring represent a powerful strategy for optimizing blue carbon management and contributing to climate change mitigation goals (Ashford et al., 2023).

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Regardless of the specific objectives pursued in the targeted area, a series of important measures must be taken into account post-assessment. Central among these measures is the active engagement of the local community, which plays an integral role in the success and longevity of conservation, restoration or sustainable use initiatives (IUCN, 2023). By involving civil society in the decision-making process and transparently communicating the planned activities in their immediate surroundings, we foster a sense of ownership and trust, ensuring that their perspectives and concerns are considered (Aguilar et al., 2015). Equipping individuals with a thorough understanding of the significance of the conservation, restoration or sustainable use efforts instills a shared responsibility for the ecosystem's well-being, encouraging active participation and support for the project (Clover & Hall, 2010). Concurrently, providing communities with comprehensive environmental education stands as a key pillar in empowering them to become environmental stewards. To provide an optimal environmental education to a community, activities such as workshops and educational talks, visits to blue carbon ecosystems or training for community leaders can be considered (Okorie & Christiana Ntente, 2021).

On the other hand, research helps to study the impact of the human activities around blue carbon ecosystems, and it informs the development of restoration and conservation strategies. Meanwhile, technology, like remote sensing satellites, drones, and underwater sensors, aids in monitoring the health and changes in these ecosystems; it also assists in identifying suitable areas for restoration, implementing restoration projects, and tracking the success of these efforts (Lanceman et al., 2022; Stephenson, 2020). These tools help researchers track carbon storage, habitat loss, and degradation, which is essential for effective conservation and management.

Research-backed data on the carbon sequestration potential of blue carbon ecosystems can attract climate financing and investment in conservation and restoration projects. This funding supports the implementation of NbS (Kuwae et al., 2022). Through effective administration of these coastal areas with blue ecosystems, countries have the opportunity to preserve and rehabilitate them. This can result in the creation of carbon credits, which are tradable in carbon markets (Goodward & Kelly, 2010). This, in turn, offers a financial motivation for enterprises and industries to allocate resources towards initiatives that uphold these environments and the communities they sustain. Embracing the sustainable use of blue carbon presents a compelling opportunity to achieve economic growth while simultaneously fostering environmental sustainability and resilience to the challenges posed by climate change (Börner et al., 2017).

The imperative transcends mere economic advancement; it encompasses the necessity to engender holistic socio-economic development. Within this paradigm, a diligent focus on law frameworks and regulatory mechanisms becomes indispensable in shaping the management of blue carbon, especially in the context of climate change mitigation and ocean policy (Hilmi et al., 2021). Blue carbon, including carbon stored in coastal ecosystems, requires a legal framework that aligns with Nationally Determined Contributions (NDCs) outlined in international agreements such as the Paris Agreement. These contributions set emission reduction targets and strategies for each country (Anisha et al., 2020; Ashford et al., 2023). Law plays a vital role by establishing guidelines for quantifying and reporting blue carbon sequestration, integrating it into national greenhouse gas inventories, and encouraging ecosystem conservation and restoration (Pham & Le Thi, 2019). Moreover, NDCs provide a platform for countries to collectively address climate change, reinforcing the importance of legal mechanisms in harmonizing blue carbon management with broader climate action agendas. In this way, law and NDCs intertwine, fostering a cohesive approach to sustainably harnessing blue carbon's potential while adhering to global climate commitments and ocean policy imperatives (Ashford et al., 2023).

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Moreover, international cooperation is vital to ensure that countries sharing blue carbon ecosystems collaborate to address common challenges and promote long-term sustainability (Ashford et al., 2023). Through engagement with international partners, collaborative research and data sharing, knowledge exchanges, partnerships with donor countries and organizations, transboundary project development, participation in blue carbon working groups, and coordinated efforts and shared responsibilities, a more holistic and effective approach to global blue carbon management can be achieved (Australian Government, 2023).

Integrating these elements into the blue carbon management plan also strengthens the implementation and enforcement of agreed-upon measures. Unifying efforts and actions lead to greater effectiveness in protecting these valuable ecosystems and their potential for climate change mitigation.

5 CONCLUSION

Optimal management involves an integral management approach, taking into consideration all types of actors in the scheme planning and decision-making processes. The convergence of scientific knowledge, civil participation, and growing political will present a timely opportunity to integrate blue carbon into mainstream climate change policy. By considering its incorporation into government climate change approaches, its full potential can be unlocked, delivering significant domestic and global benefits.

The efficient management practices mentioned will be important in realizing the potential of blue carbon sequestration. The success of such endeavors will not only yield benefits on a domestic scale, but also elevate pioneer countries as world leaders in this sphere of environmental stewardship.

Furthermore, blue carbon's emergence as a potential source of projects under various international agreements opens up possibilities for pilot projects to be explored and examined in early scientific studies. This proactive approach will help assess the feasibility of implementing blue carbon initiatives on a broader scale.

As we move forward, the integration of blue carbon into climate change policy must prioritize the active engagement of all stakeholders, particularly the local communities whose participation and support are essential for long-term success. Conclusively, an inclusive and harmonized regulatory framework, underpinned by international cooperation, will be pivotal in effectively protecting and conserving blue carbon ecosystems that span across national borders.

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REFERENCES

Aguilar, O., Price, A., & Krasny, M. (2015). Perspectives on community environmental education. In Monroe, M. C., and Krasny, M. E. (Eds.), *Across the Spectrum: Resources for Environmental Educators* (2nd ed., chapter 9). North American Association for Environmental Education. https://www.researchgate.net/profile/Kirsten-Hecht/publication/282021995_Connecting_with_parents_to_connect_children_to_nature/links/56018cff08aeb30ba735041e/Connecting-with-parents-to-connect-children-to-nature.pdf

Alongi, D. M. (2012). Carbon sequestration in mangrove forests. *Carbon Management, 3*(3), 313-322. https://doi.org/10.4155/cmt.12.20

Anisha, N. F., Mauroner, A., Lovett, G., Neher, A., Servos, M., Minayeva, T., Schutten, H., & Minelli, L. (2020). *Locking Carbon in Wetlands for Enhanced Climate Action in NDCs.* Corvallis, Oregon and Wageningen, The Netherlands: Alliance for Global Water Adaptation and Wetlands International.

Ashford, O. S., Bonotto, E., Cifuentes-Jara, M., Glass, L., Howard, J., Landis, E., Northrop, E., Roth, N., & Thiele, T. (2023). *The blue carbon handbook: Blue carbon as a nature-based solution for climate action and sustainable development.* High Level Panel for a Sustainable Ocean Economy. https://oceanpanel.org/wp-content/uploads/2023/06/Ocean_Panel_Blue_Carbon_Handbook-1.pdf

Atalla, G., Mills, M., & McQueen, J. (2022, May 13). *Six ways that governments can drive the green transition.* EY - Building a Better Working World. Retrieved August 12, 2023, from https://www.ey.com/en_gl/government-public-sector/six-ways-that-governments-can-drive-the-green-transition

Australian Government (2023, May 26). *The International Partnership for Blue Carbon.* Department of Climate Change, Energy, the Environment and Water. Retrieved July 30, 2023, from https://www.dcceew.gov.au/climate-change/policy/ocean-sustainability/coastal-blue-carbon-ecosystems/ipbc

Baker, J., Sheate, W. R., Phillips, P., & Eales, R. (2013). Ecosystem services in environmental assessment — Help or hindrance? *Environmental Impact Assessment Review, 40,* 3-13. https://doi.org/10.1016/j.eiar.2012.11.004

Bandh, S. A., Malla, F. A., Qayoom, I., Mohi-Ud-Din, H., Butt, A. K., Altaf, A., Wani, S. A., Betts, R., Truong, T. H., Pham, N. D. K., Cao, D. N., & Ahmed, S. F. (2023). Importance of Blue Carbon in Mitigating Climate Change and Plastic/Microplastic Pollution and Promoting Circular Economy. *Sustainability, 15*(3), 2682. http://dx.doi.org/10.3390/su15032682

Beaumont, N. J., Jones, L., Garbutt, A., Hansom, J. D., & Tobermann, M. (2014). The value of carbon sequestration and storage in coastal habitats. *Estuarine, Coastal and Shelf Science, 137*(1), 32-40. https://doi.org/10.1016/j.ecss.2013.11.022

Börner, J., Baylis, K., Corbera, E., Ezzine-de-Blas, D., Honey-Rosés, J., Persson, U. M., & Wunder, S. (2017). The effectiveness of payments for environmental services. *World Development. 96,* 359-374. https://doi.org/10.1016/j.worlddev.2017.03.020

DOI: 10.29677/MR.202312_3(2).0003

Borrini-Feyerabend, G., Dudley, N., Jaeger, T., Lassen, B., Broome, N. P., Phillips, A. & Sandwith. T. (2021). Governance of Protected Areas: From understanding to action. *IUCN Best Practice Protected Area Guidelines Series, 20,* 1-144. https://portals.iucn.org/library/sites/library/files/documents/PAG-020.pdf

Brogan, C. (2022, July 19). *Carbon captured and stored since 1996 is significant but overestimated.* Imperial College London. https://www.imperial.ac.uk/news/238411/carbon-captured-stored-since-1996-significant/

Bryan, T., Virdin, J., Vegh, T., Kot, C. Y., Cleary, J., & Halpin, P. N. (2020). Blue carbon conservation in West Africa: A first assessment of feasibility. *Journal of Coastal Conservation, 24*(8). https://doi.org/10.1007/s11852-019-00722-x

Carbon Gap. (2022, November 16). *The difference between CCS, CCU, and CDR – and why it matters.* Carbon Gap. https://carbongap.org/the-difference-between-ccs-ccu-and-cdr-and-why-it-matters/

Carlson, R. R., Evans, L. J., Foo, S. A., Grady, B. W., Li, J., Seeley, M., Xu, Y., & Asner, G. P. (2021). Synergistic benefits of conserving land-sea ecosystems. *Global Ecology and Conservation, 28,* e01684. https://doi.org/10.1016/j.gecco.2021.e01684

Clover, D. E., & Hall, B. L. (2010). Critique, Create and Act: Environmental Adult and Social Movement Learning in an Era of Climate Change. In Kagawa, F., and Selby, D. (Eds.), *Education and Climate Change: Living and Learning in Interesting Times* (1st ed., Chapter 9): New York.

Colvin, R. M., Bradd Witt, G., & Lacey, J. (2016). Approaches to identifying stakeholders in environmental management: Insights from practitioners to go beyond the "usual suspects". *Land Use Policy, 52,* 266-276. https://doi.org/10.1016/j.landusepol.2015.12.032

Dellesky, C. (2023, March 23). *Carbon Removal.* World Resources Institute. Retrieved August 5, 2023, from https://www.wri.org/initiatives/carbon-removal#:~:text=Carbon%20removal%20methods%20include%20natural,and%20ocean%2Dbased%20carbon%20removal

Denchak, M. (2023, June 5). *Greenhouse Effect 101*. Natural Resources Defense Council. https://www.nrdc.org/stories/greenhouse-effect-101#whatis

Dudley, N., Jonas, H., Nelson, F., Parrish, J., Pyhälä, A., Stolton, S., & Watson, J. E. M. (2018). The essential role of other effective area-based conservation measures in achieving big bold conservation targets. *Global Ecology and Conservation, 15,* e00424. https://doi.org/10.1016/j.gecco.2018.e00424

De Jesús Arce-Mojica, T., Nehren, U., Sudmeier-Rieux, K., Miranda, P. J., & Anhuf, D. (2019). Nature-based solutions (NbS) for reducing the risk of shallow landslides: Where do we stand? *International Journal of Disaster Risk Reduction, 41,* 101293. https://doi.org/10.1016/j.ijdrr.2019.101293

Edler, J., Karaulova, M., & Barker, K. (2022). Understanding Conceptual Impact of Scientific Knowledge on Policy: The Role of Policymaking Conditions. *Minerva, 60,* 209-233. https://doi.org/10.1007/s11024-022-09459-8

Fennessy, S., & Beers, L. (2023). The contribution of blue carbon ecosystems to climate change mitigation. *Ramsar Briefing Note 12.* https://doi.org/10.13140/RG.2.2.17891.22565

Goodward, J., & Kelly, A. (2010). *Bottom Line on Offsets.* World Resources Institute. https://www.wri.org/research/bottom-line-offsets

Marine Research of the National Academy of Marine Research
DOI: 10.29677/MR.202312_3(2).0003

Harvey, F. (2023, April 25). *Carbon dioxide removal: The tech that is polarising climate science.* The Guardian. https://www.theguardian.com/environment/2023/apr/25/carbon-dioxide-removal-tech-polarising-climate-science

Herrmann-Pillath, C., Hiedanpää, J., & Soini, K. (2022). The co-evolutionary approach to nature-based solutions: A conceptual framework. *Nature-Based Solutions, 2,* 100011. https://doi.org/10.1016/j.nbsj.2022.100011

Hilmi, N., Chami, R., Sutherland, M. D., Hall-Spencer, J. M., Lebleu, L., Benitez, M. B., & Levin, L. A. (2021). The Role of Blue Carbon in Climate Change Mitigation and Carbon Stock Conservation. *Frontiers in Climate, 3.* https://doi.org/10.3389/fclim.2021.710546

Intergovernmental Panel on Climate Change (IPCC). (2023). Annex VII: Glossary. In Matthews, J. B. R., Matthews, J. B. R., Möller, V., van Diemen, R., Fuglestvedt, J. S., Masson-Delmotte, V., Méndez, C., Semenov, S., and Reisinger, A. (Eds.), *Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 2215-2256). Cambridge: Cambridge University Press. https://doi.org/10.1017/9781009157896.022

IUCN (2023, August 1). *Local communities - Leading the charge towards mangroves conservation and restoration.* IUCN. https://www.iucn.org/blog/202308/local-communities-leading-charge-towards-mangroves-conservation-and-restoration

Karstens, S., Schernewski, G., & Inácio, M. (2019). Expert-Based Evaluation of Ecosystem Service Provision in Coastal Reed Wetlands Under Different Management Regimes. *Frontiers in Environmental Science, 7.* https://doi.org/10.3389/fenvs.2019.00063

Keller, D. P., Lenton, A., Littleton, E. W., Oschlies, A., Scott, V., & Vaughan, N. E. (2018). The Effects of Carbon Dioxide Removal on the Carbon Cycle. *Current Climate Change Reports, 4,* 250-265. https://doi.org/10.1007/s40641-018-0104-3

Kuwae, T., Watanabe, A., Yoshihara, S., Suehiro, F., & Sugimura, Y. (2022). Implementation of blue carbon offset crediting for seagrass meadows, macroalgal beds, and macroalgae farming in Japan. *Marine Policy, 138,* 104996. https://doi.org/10.1016/j.marpol.2022.104996

Lanceman, D., Sadat-Noori, M., Gaston, T., Drummond, C., & Glamore, W. (2022). Blue carbon ecosystem monitoring using remote sensing reveals wetland restoration pathways. *Frontiers in Environmental Science, 10.* https://doi.org/10.3389/fenvs.2022.924221

Langlet, D., & Rayfuse, R. (2019). *The ecosystem approach in ocean planning and governance: Perspectives from Europe and beyond.* Brill | Nijhoff. Publications on Ocean Development (Vol. 87). https://maritime-spatial-planning.ec.europa.eu/sites/default/files/9789004389984_-_the_ecosystem_approach_in_ocean_planning_and_governance_the_ecosystem_approach_in_ocean_planning_and_governance.pdf

Levin, P. S., Fogarty, M. J., Murawski, S. A., & Fluharty, D. (2009). Integrated Ecosystem Assessments: Developing the Scientific Basis for Ecosystem-Based Management of the Ocean. *PLOS Biology, 7*(1), e1000014. https://doi.org/10.1371/journal.pbio.1000014

Mackey, B., Keith, H., Berry, S. L., & Lindenmayer, D. B. (2008). *Green Carbon Part 1 The role of natural forests in carbon storage.* ANU Press, Australia. http://doi.org/10.22459/GC.08.2008

Macreadie, P. I., Anton, A., Raven, J. A., Beaumont, N., Connolly, R. M., Friess, D. A., Kelleway, J. J.,Kennedy, H., Kuwae, T., Lavery, P. S., Lovelock, C. E., Smale, D. A., Apostolaki, E. T., Atwood, T. B., Baldock, J.,Bianchi, T. S., Chmura, G. L., Eyre, B. D., Fourqurean, J. W., Hall-Spencer, J. M., Huxham, M., Hendriks,I. E., Krause-Jensen, D., Laffoley, D., Luisetti, T., Marbà, N., Masque, P., McGlathery, K. J., Megonigal,J. P.,Murdiyarso, D., Russell, B. D., Santos, R., Serrano, O., Silliman, B. R., Watanabe, K., & Duarte, C. M. (2019).The future of Blue Carbon Science. *Nature Communications 10,* 3998, http://doi.org/10.1038/s41467-019-11693-w

Martin-Roberts, E., Scott, V., Flude, S., Johnson, G., Haszeldine, R. S., & Gilfillan, S. (2021). Carbon capture and storage at the end of a lost decade. *One Earth, 4*(11), 1569-1584. https://doi.org/10.1016/j.oneear.2021.10.002

Nellemann, C., Corcoran, E., Duarte, C. M., Valdrés, L., De Young, C., Fonseca, L., & Grimsditch, G. (2009). *Blue Carbon: The Role of Healthy Oceans in Binding Carbon.* UNEP. https://wedocs.unep.org/20.500.11822/7772

Okorie, C. U. & Christiana Ntente, I. (2021). Community based environmental education a strategy for mitigating impacts of climate change on livelihood of riverine communities in rivers state. *International Journal of Weather, Climate Change and Conservation Research, 7*(1), 45-54.

Ontl, T. A., & Schulte, L. A. (2012). Soil Carbon Storage. *Nature Education Knowledge, 3*(10), 35. https://www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790/

Pham, T. T. & Le Thi, T. T. (2019). Incorporating blue carbon into Nationally Determined Contributions. *Center for International Forestry Research.* https://doi.org/10.17528/cifor/007554

Rehbein, J., Encalada, G. & Barbosa, J. (2020). *Evaluación bibliográfica del potencial de mitigación y adaptación al cambio climático de los ecosistemas marinos.* World Bank, Santiago, Chile. https://documents1.worldbank.org/curated/en/639801592984216703/pdf/Evaluacion-bibliografica-del-potencial-de-mitigacion-y-adaptacion-al-cambio-clim%C3%A1tico-de-los-ecosistemas-marinos.pdf

Samaniego, J., Lorenzo, S., Rondón Toro, E., Krieger Merico, L. F., Herrera Jiménez, J., Rouse, P., & Harrison, N. (2023). *Nature-based solutions and carbon dioxide removal.* United Nations. Economic Commission for Latin America and the Caribbean. https://hdl.handle.net/11362/48691

Stephenson, P. (2020). Technological advances in biodiversity monitoring: applicability, opportunities and challenges. *Current Opinion in Environmental Sustainability, 45,* 36-41. https://doi.org/10.1016/j.cosust.2020.08.005

Sullivan, C. M., Conway, F. D. L., Pomeroy, C., Hall-Arber, M., & Wright, D. J. (2015). Combining geographic information systems and ethnography to better understand and plan ocean space use. *Applied Geography, 59,* 70-77. https://doi.org/10.1016/j.apgeog.2014.11.027

Tcvetkov, P., Cherepovitsyn, A., & Fedoseev, S. (2019). The Changing Role of CO2 in the Transition to a Circular Economy: Review of Carbon Sequestration Projects. *Sustainability, 11*(20), 5834. https://doi.org/10.3390/su11205834

Wellmann, T., Andersson, E., Knapp, S., Lausch, A., Palliwoda, J., Priess, J., Scheuer, S., & Haase, D. (2023). Reinforcing nature-based solutions through tools providing social-ecological-technological integration. *Ambio, 52,* 489-507. https://doi.org/10.1007/s13280-022-01801-4