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Mangrove Blue Carbon, Coastal Biogeochemistry, and Ecosystem Resilience: A Comparative Analysis of Tropical Deltaic and Island Mangrove Systems

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ABSTRACT

Mangrove ecosystems are among the most carbon-dense coastal environments, yet their capacity to store carbon and sustain ecological resilience varies strongly across geomorphic, hydrological, and anthropogenic contexts. This study examines how tropical deltaic and island mangrove systems differ in blue carbon accumulation, sediment biogeochemistry, biodiversity function, and vulnerability to climate and land-use pressures. The article argues that mangrove carbon storage cannot be explained solely by vegetation biomass because sediment accretion, tidal exchange, salinity gradients, root architecture, microbial decomposition, and disturbance regimes jointly regulate long-term carbon persistence. Using comparative environmental analysis, coastal biogeochemistry synthesis, remote-sensing evidence, peer-reviewed mangrove carbon literature, and international climate and biodiversity reports, the study evaluates deltaic mangroves and island mangroves as contrasting but complementary coastal systems. The findings indicate that deltaic mangroves often exhibit high sediment carbon accumulation due to riverine sediment supply and organic matter burial, but are vulnerable to upstream damming, conversion, pollution, and subsidence. Island mangroves may exhibit lower sediment input but stronger dependence on tidal exchange, carbonate dynamics, salinity regulation, and reef–seagrass connectivity. This article contributes to natural sciences scholarship by integrating coastal geomorphology, soil biogeochemistry, plant ecology, climate mitigation science, and sustainability-oriented conservation into a unified framework for understanding mangrove blue carbon resilience.

Keywords: mangroves; blue carbon; coastal biogeochemistry; sediment carbon; ecosystem resilience; climate mitigation; coastal wetlands; biodiversity; sea-level rise; sustainability science

INTRODUCTION

Mangrove forests occupy intertidal zones across tropical and subtropical coastlines and provide critical ecological, climatic, and socio-economic functions. They protect shorelines from erosion and storm surge, support fisheries, regulate sediment transport, sustain biodiversity, filter pollutants, and store large quantities of carbon in biomass and waterlogged sediments (Alongi, 2014; Friess et al., 2019). Their carbon storage function has attracted increasing scientific and policy attention because coastal vegetated ecosystems, including mangroves, seagrasses, and tidal marshes, store "blue carbon" at rates that can exceed many terrestrial forests when sediment accumulation is considered (Donato et al., 2011; Macreadie et al., 2021).

The global environmental context is urgent. Climate change is accelerating sea-level rise, intensifying tropical cyclone risks in some regions, increasing coastal erosion, and altering precipitation and salinity regimes (IPCC, 2023). At the same time, mangroves remain threatened by aquaculture expansion, urban development, agriculture, timber extraction, hydrological alteration, and pollution (Goldberg et al., 2020; UNEP, 2023). Although global mangrove loss rates have slowed in some regions due to conservation policies and restoration efforts, many mangrove landscapes remain fragmented and degraded (Bunting et al., 2022). Loss of mangroves releases stored carbon, reduces biodiversity, increases coastal vulnerability, and undermines climate adaptation capacity.

The scientific importance of mangrove blue carbon lies in the interaction between biological productivity and sedimentary carbon preservation. Mangroves fix atmospheric carbon through photosynthesis and allocate substantial biomass belowground through roots, rhizomes, and organic exudates. Anaerobic, saline, and waterlogged sediments slow organic matter decomposition, allowing carbon accumulation over decades to millennia (Kristensen et al., 2008; Alongi, 2014). However, carbon storage varies substantially across geomorphic settings, tidal regimes, sediment supply, nutrient availability, salinity, species composition, microbial processes, and disturbance history.

This variation creates a core scientific problem: mangrove carbon accounting often relies on generalized carbon density values, yet actual blue carbon persistence depends on system-specific biogeochemical mechanisms. Deltaic mangroves and island mangroves illustrate this complexity. Deltaic mangroves, often located near major river systems, receive high sediment and nutrient inputs that can promote vertical accretion and carbon burial. However, they are vulnerable to upstream sediment trapping, subsidence, pollution, land conversion, and altered freshwater flows. Island mangroves, including those in reef-associated or carbonate settings, may receive less terrigenous sediment but can depend strongly on tidal flushing, groundwater exchange, reef protection, and interactions with seagrass and coral systems.

Existing literature provides important foundations. Donato et al. (2011) demonstrated that mangroves are among the most carbon-rich forests globally, with substantial carbon stored in organic-rich soils. Alongi (2014) synthesized mangrove carbon cycling and highlighted the importance of sediment processes. Friess et al. (2019) emphasized that mangroves provide multiple ecosystem services beyond carbon storage. Macreadie et al. (2021) argued that blue carbon ecosystems are increasingly important for climate mitigation but require robust measurement and governance frameworks. Other researchers show that mangrove restoration success depends on hydrological suitability rather than planting alone (Primavera & Esteban, 2008; Lovelock & Reef, 2020).

While previous studies emphasize global carbon stocks and restoration potential, current natural sciences literature remains limited in explaining how geomorphic setting modifies mangrove carbon sequestration mechanisms. Many studies compare mangroves with terrestrial forests but less frequently compare different mangrove system types. Existing scientific scholarship also remains limited in integrating sediment biogeochemistry, microbial decomposition, sea-level rise, biodiversity function, and restoration feasibility within a single comparative framework.

Several research gaps remain. First, theoretical models of blue carbon often insufficiently represent geomorphic controls on sediment accretion and carbon preservation. Second, empirical carbon estimates are unevenly distributed across regions and habitat types, creating uncertainty in global accounting. Third, comparative analysis of deltaic and island mangroves remains underdeveloped despite their different hydrological and sedimentary processes. Fourth, restoration literature often emphasizes area recovery without adequately evaluating long-term carbon permanence and ecological function. Fifth, measurement and validation challenges remain because soil carbon depth, bulk density, allochthonous carbon input, and disturbance history are difficult to standardize.

This article addresses these gaps by developing a comparative environmental analysis of tropical deltaic and island mangrove systems. The study integrates coastal geomorphology, sediment biogeochemistry, plant ecology, microbial decomposition theory, climate adaptation science, and sustainability-oriented conservation. It does not fabricate primary field measurements; rather, it synthesizes empirically verifiable evidence from peer-reviewed mangrove carbon studies, remote-sensing assessments, IPCC climate synthesis, UNEP coastal ecosystem reports, and international blue carbon literature.

The novelty of this article lies in conceptualizing mangrove blue carbon resilience as a geomorphically mediated biogeochemical process rather than a simple function of mangrove area or vegetation biomass. The article argues that long-term carbon storage depends on the coupling between primary production, sediment trapping, tidal hydrology, root architecture, microbial decomposition, mineral association, and disturbance avoidance.

The analytical framework follows the causal pathway: coastal geomorphic setting → hydrological and sedimentary regime → biogeochemical carbon processing → ecological resilience → climate mitigation and sustainability outcomes. In deltaic systems, riverine sediment supply and organic matter burial may enhance carbon accumulation but increase vulnerability to upstream hydrological alteration. In island systems, tidal exchange, salinity control, and ecological connectivity may regulate resilience despite lower sediment inputs.

This study aims to analyze comparatively how tropical deltaic and island mangrove systems differ in blue carbon accumulation, sediment biogeochemistry, ecological resilience, and vulnerability to climate and anthropogenic stressors.

METHODOLOGY

This study employs a comparative interdisciplinary environmental research design integrating coastal biogeochemistry, geomorphic systems analysis, plant ecology, remote-sensing interpretation, and sustainability-oriented conservation assessment to evaluate blue carbon dynamics in tropical deltaic and island mangrove systems. These two systems were selected because they represent contrasting coastal configurations with different sediment sources, hydrological regimes, salinity gradients, disturbance pathways, and ecological connectivity. Deltaic mangroves are characterized by riverine sediment delivery, freshwater influence, high nutrient flux, and potential subsidence or land conversion pressures, whereas island mangroves are often shaped by tidal exchange, carbonate sediment dynamics, reef or seagrass connectivity, limited terrigenous input, and high sensitivity to sea-level rise and salinity stress. The unit of analysis consists of mangrove ecosystem carbon function, including aboveground biomass, belowground root production, sediment organic carbon accumulation, microbial decomposition, accretion capacity, and resilience under environmental disturbance. Analytical variables include sediment supply, tidal inundation frequency, soil carbon density, bulk density, redox conditions, salinity, root biomass allocation, microbial respiration, methane and carbon dioxide fluxes, species composition, canopy structure, land-use pressure, restoration feasibility, and sea-level rise exposure.

The empirical foundation is derived from peer-reviewed mangrove blue carbon studies, soil carbon inventories, sediment accretion research, remote-sensing mangrove extent datasets, IPCC climate assessments, UNEP coastal ecosystem reports, Global Mangrove Watch products, and biodiversity literature published across coastal science, ecology, and biogeochemistry. Comparative interpretation prioritized convergent evidence rather than fabricated field measurements, distinguishing directly measured carbon stock patterns from mechanism-based inference where site heterogeneity remains high. Analytical triangulation was performed by connecting carbon stock literature with hydrological, geomorphic, and ecological evidence. Validation and reproducibility were addressed by emphasizing standardized blue carbon measurement principles, including soil depth, bulk density, organic carbon concentration, and ecosystem boundary definitions. Ethical and environmental considerations include avoiding unsupported claims about carbon credits, recognizing community dependence on mangrove ecosystems, and emphasizing restoration strategies that preserve hydrological function and biodiversity rather than monoculture planting. The study is limited by uneven spatial data coverage, differences in soil sampling depth, and uncertainty in long-term carbon permanence under sea-level rise, but it provides analytically robust insight into system-specific blue carbon resilience.

Findings and Discussion

1. Geomorphic Setting and Sediment-Mediated Carbon Accumulation

The comparative evidence demonstrates that geomorphic setting strongly influences mangrove carbon accumulation. Deltaic mangroves often receive high sediment loads from rivers, which promote soil formation, vertical accretion, and organic matter burial. Riverine sediments can increase mineral surface availability for organic carbon stabilization and help mangroves maintain elevation relative to sea-level rise. This makes sediment supply a central control on carbon persistence in deltaic systems (Alongi, 2014; Rogers et al., 2019).

However, deltaic advantages are increasingly threatened by upstream damming, river channelization, sediment mining, groundwater extraction, and land subsidence. When sediment delivery declines, deltaic mangroves may lose elevation capital, increasing vulnerability to inundation and erosion. Thus, high carbon accumulation potential does not automatically translate into long-term resilience. It depends on continued sediment connectivity and hydrological integrity.

Island mangroves generally receive lower terrigenous sediment inputs, especially in carbonate or reef-associated settings. Their carbon accumulation depends more strongly on autochthonous organic matter production, root accumulation, tidal exchange, and local sediment trapping. Although sediment inputs may be lower, island mangroves can maintain high carbon density when hydrological conditions create anoxic sediment environments that slow decomposition.

Cross-system comparison reveals that deltaic mangroves may accumulate carbon rapidly where sediment and organic matter burial are sustained, whereas island mangroves may rely more heavily on biological productivity and sediment retention efficiency. This distinction is important because restoration and carbon accounting strategies must not apply a single mangrove carbon model across all geomorphic contexts.

These findings support blue carbon studies showing that mangrove soils contain substantial carbon stocks but vary widely by location and sediment environment (Donato et al., 2011; Macreadie et al., 2021). They extend previous scholarship by emphasizing geomorphic mechanism rather than average carbon density.

Scientifically, the implication is that carbon models should integrate sediment budgets, accretion rates, and hydrological connectivity. Environmentally, protecting upstream sediment delivery may be as important as protecting mangrove vegetation itself in deltaic landscapes.

2. Root Architecture, Microbial Decomposition, and Sediment Biogeochemistry

Mangrove carbon storage is strongly controlled by belowground processes. Root production contributes organic matter directly to sediments, while waterlogging and low oxygen availability slow decomposition. Salinity and sulfate availability influence microbial pathways, including sulfate reduction, methanogenesis, and carbon dioxide production (Kristensen et al., 2008).

Deltaic mangroves often have strong belowground carbon inputs combined with mineral sediment burial. Fine sediments can protect organic matter by reducing oxygen diffusion and promoting mineral–organic associations. However, nutrient enrichment from rivers may accelerate microbial decomposition under some conditions, potentially increasing carbon turnover if organic matter becomes more labile.

Island mangroves may experience stronger salinity stress and lower nutrient input. Under moderate stress, plants often allocate more biomass belowground, potentially increasing root-derived carbon input. However, extreme salinity can reduce productivity and impair seedling establishment. Microbial decomposition in island systems is also shaped by tidal flushing and carbonate chemistry, which may influence carbon preservation differently from muddy deltaic sediments.

The comparative evidence reveals that microbial decomposition is not simply suppressed in all mangrove soils. It varies with redox potential, salinity, temperature, nutrient availability, organic matter quality, and tidal exchange. Therefore, blue carbon persistence depends on microbial metabolism as much as plant biomass.

This finding aligns with contemporary soil and sediment carbon theory emphasizing that carbon persistence results from environmental constraints and mineral protection rather than inherent recalcitrance alone (Lehmann & Kleber, 2015). In mangrove sediments, anoxia, mineral binding, and continuous burial jointly contribute to carbon stabilization.

Scientific implications include the need for greater integration of microbial ecology into blue carbon monitoring. Measuring biomass and soil carbon alone is insufficient if decomposition rates, greenhouse gas fluxes, and microbial pathways remain unknown. Environmental implications include the need to protect hydrology because drainage or conversion can rapidly oxidize stored carbon and release greenhouse gases.

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3. Comparative Matrix of Experimental Variables, Mechanisms, and Outcomes

Table 1. Comparative Matrix of Experimental Variables, Scientific Mechanisms, and Measurable Outcomes

Variable	Case/System 1: Tropical Deltaic Mangroves	Case/System 2: Island Mangrove Systems	Empirical Evidence	Analytical Interpretation
Sediment supply	High riverine sediment and nutrient input	Lower terrigenous input, stronger tidal dependence	Sediment accretion and blue carbon studies	Sediment regime controls vertical accretion and carbon burial
Carbon	Mineral	Root	Mangrove	Carbon

accumulation mechanism	sediment burial plus root organic matter	production, local trapping, tidal and carbonate dynamics	soil carbon inventories	storage pathways differ by geomorphic setting
Hydrological control	Freshwater–saltwater gradients and river discharge	Tidal exchange, groundwater influence, salinity regulation	Coastal hydrology literature	Hydrology determines redox conditions and decomposition pathways
Vulnerability	Damming, subsidence, conversion, pollution	Sea-level rise, erosion, salinity stress, storm exposure	IPCC and UNEP coastal assessments	Stress pathways differ by coastal configuration
Microbial process	Decomposition mediated by nutrient input and anoxia	Decomposition mediated by salinity, tidal flushing, carbonate chemistry	Sediment biogeochemistry studies	Microbial carbon cycling is system-specific
Biodiversity function	Nursery habitat and deltaic productivity	Reef–seagrass–mangrove connectivity and island habitat networks	Coastal ecology literature	Ecological connectivity shapes resilience and recovery
Restoration constraint	Requires hydrological reconnection and sediment delivery	Requires elevation suitability and tidal exchange	Restoration ecology literature	Planting alone is insufficient without physical suitability
Sustainability implication	High carbon mitigation potential but high land-use risk	Strong adaptation value but high sea-level sensitivity	Blue carbon and climate adaptation literature	Conservation priorities must be geomorphically targeted

The matrix demonstrates that deltaic and island mangroves are not interchangeable blue carbon systems. Deltaic mangroves may offer high carbon accumulation potential because riverine sediments and organic matter burial support soil formation. However, their carbon permanence depends strongly on upstream sediment delivery and avoidance of subsidence or conversion. Island mangroves may accumulate carbon through root production and local sediment trapping, but their resilience depends on tidal exchange, elevation, salinity balance, and ecological connectivity.

This comparative interpretation challenges simplified carbon accounting approaches that estimate blue carbon primarily by mangrove area. Area is important, but carbon function is mediated by geomorphology and biogeochemistry. A small island mangrove with persistent anoxic sediment and stable hydrology may store carbon effectively, while a degraded deltaic mangrove experiencing subsidence and hydrological disruption may lose carbon despite large area.

The table also shows that restoration success requires physical suitability. Planting mangroves in areas lacking appropriate tidal elevation or sediment dynamics may fail or produce low ecological value. This supports restoration literature emphasizing hydrological rehabilitation over planting-centered approaches (Primavera & Esteban, 2008; Lovelock & Reef, 2020).

Scientifically, future blue carbon research should include sediment accretion measurements, microbial respiration, soil depth profiles, hydrological monitoring, and remote-sensing validation. Environmentally, carbon-credit schemes must incorporate permanence risk, leakage, biodiversity integrity, and community governance.

4. Sea-Level Rise, Disturbance Regimes, and Ecosystem Resilience

Sea-level rise represents a major threat to mangrove resilience. Mangroves can persist if vertical accretion and landward migration keep pace with rising sea levels. However, this depends on sediment supply, root production, accommodation space, tidal range, and absence of barriers such as seawalls or urban development (IPCC, 2023).

Deltaic mangroves may be highly resilient when sediment supply is sufficient, but highly vulnerable when subsidence exceeds accretion. Many deltas are experiencing reduced sediment delivery due to dams and river engineering. This reduces the ability of mangroves to maintain elevation and increases the risk of drowning or conversion to open water.

Island mangroves face different constraints. Limited land area, steep topography, coastal development, and reef degradation can restrict landward migration. Storm surges and cyclones may cause episodic damage, but mangroves can also reduce wave energy and protect island shorelines. Their resilience depends on ecological connectivity with coral reefs and seagrasses, which can reduce hydrodynamic stress and support sediment stability.

The comparative evidence indicates that resilience is not simply resistance to disturbance. It includes the capacity to recover, migrate, accrete, regenerate, and maintain ecological function under changing boundary conditions. Deltaic resilience depends strongly on sediment continuity, whereas island resilience depends strongly on spatial accommodation and coastal habitat connectivity.

These findings align with coastal resilience theory, which emphasizes dynamic feedbacks between vegetation, sediments, hydrology, and disturbance regimes (Rogers et al., 2019). They also extend blue carbon scholarship by linking carbon permanence to geomorphic resilience under sea-level rise.

The implication is that conservation strategies must be anticipatory. Protecting present mangrove extent is insufficient if future migration corridors are blocked. Coastal planning must preserve accommodation space, sediment pathways, and habitat connectivity.

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5. Climate Mitigation, Biodiversity, and Sustainability Implications

Mangroves are frequently promoted as natural climate solutions because they store carbon and provide adaptation benefits. However, their mitigation value depends on carbon permanence, avoided emissions, ecological integrity, and governance credibility. Degraded or converted mangroves can release substantial carbon from biomass and sediments, making conservation often more effective than restoration for near-term climate mitigation (Murdiyarso et al., 2015; Macreadie et al., 2021).

Deltaic mangroves may offer substantial mitigation value due to large sediment carbon pools. Preventing conversion to aquaculture, agriculture, or urban land can avoid major emissions. However, if upstream sediment supply is reduced, long-term carbon permanence may be compromised.

Island mangroves may be especially important for climate adaptation and biodiversity connectivity. Their role in shoreline protection, fish nursery habitat, and reef–seagrass connectivity can support ecosystem resilience even where carbon stocks are lower than deltaic systems. This demonstrates that blue carbon valuation should not reduce mangrove importance to carbon alone.

The comparative evidence indicates that mangrove sustainability requires integrating climate mitigation, adaptation, biodiversity, and community livelihoods. Carbon-focused restoration that ignores species diversity, hydrology, or local resource dependence may produce poor ecological outcomes. Conversely, community-based conservation can support both ecological resilience and socio-economic sustainability when governance is equitable.

This article contributes to natural sciences scholarship by demonstrating that mangrove blue carbon is a coupled biogeochemical and socio-ecological phenomenon. Scientifically robust carbon accounting must include sediment processes, microbial decomposition, hydrological dynamics, biodiversity function, and disturbance risk.

Scientific Propositions

Proposition 1: Mangrove blue carbon accumulation is mediated by geomorphic setting through sediment supply, tidal hydrology, and root-derived organic matter burial.

Deltaic and island mangroves store carbon through different but interacting mechanisms, requiring system-specific carbon models.

Proposition 2: Sediment biogeochemistry mediates the relationship between mangrove productivity and long-term carbon persistence.

Carbon storage depends not only on biomass production but also on redox conditions, microbial decomposition, salinity, mineral association, and burial rates.

Proposition 3: Mangrove resilience under sea-level rise depends on the balance between vertical accretion, landward migration, and disturbance exposure.

Systems with sufficient sediment supply or accommodation space are more likely to maintain ecological function.

Proposition 4: Blue carbon sustainability requires integrating climate mitigation, biodiversity conservation, hydrological integrity, and community governance.

Carbon storage alone is insufficient as a success metric if restoration reduces ecological complexity or ignores long-term permanence risk.

CONCLUSION

This study analyzed how tropical deltaic and island mangrove systems differ in blue carbon accumulation, sediment biogeochemistry, ecological resilience, and vulnerability to climate and anthropogenic stressors. The findings demonstrate that mangrove carbon storage is not determined solely by forest area or vegetation biomass. Instead, it emerges from interactions among geomorphic setting, sediment supply, tidal hydrology, root architecture, microbial decomposition, salinity, and disturbance history.

Deltaic mangroves often possess high carbon accumulation potential due to riverine sediment delivery, mineral-associated carbon stabilization, and organic matter burial. However, they are highly vulnerable to upstream damming, sediment starvation, subsidence, pollution, and land conversion. Island mangroves may receive lower terrigenous sediment inputs but can maintain important carbon and adaptation functions through tidal exchange, root production, local sediment trapping, and ecological connectivity with reefs and seagrasses.

The theoretical contribution of this article lies in reframing mangrove blue carbon as a geomorphically mediated biogeochemical process. The empirical contribution lies in synthesizing evidence from carbon stock studies, sediment biogeochemistry, remote sensing, restoration ecology, and international climate assessments to explain why mangrove carbon outcomes vary across coastal settings.

The environmental implication is that mangrove conservation and restoration must be system-specific. Deltaic systems require protection of sediment pathways and prevention of land conversion. Island systems require preservation of tidal exchange, migration space, shoreline connectivity, and salinity balance. Restoration should prioritize hydrological suitability and ecological function rather than planting density alone.

The study is limited by reliance on secondary evidence and by uneven global sampling of mangrove soil carbon and sediment processes. Future research should expand long-term monitoring of accretion, microbial respiration, greenhouse gas fluxes, sediment origin, and carbon permanence under sea-level rise.

Integrating remote sensing, field biogeochemistry, isotope tracing, and community-based monitoring will be essential.

Ultimately, this article argues that mangroves are not merely carbon reservoirs but dynamic coastal biogeochemical systems whose resilience depends on maintaining the physical and ecological processes that enable carbon accumulation, biodiversity support, and climate adaptation.

REFERENCES

Alongi, D. M. (2014). Carbon cycling and storage in mangrove forests. Annual Review of Marine Science, 6, 195–219.

Alongi, D. M. (2020). Global significance of mangrove blue carbon in climate change mitigation. Science of the Total Environment, 728, 138961.

Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R. M., Thomas, N., Tadono, T., Worthington, T. A., Spalding, M., Murray, N. J., & Rebelo, L. M. (2022). Global Mangrove Watch: Updated 2010 mangrove forest extent and changes. Remote Sensing, 14(4), 1034.

Donato, D. C., Kauffnan, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. Nature Geoscience, 4, 293–297.

Friess, D. A., Rogers, K., Lovelock, C. E., Krauss, K. W., Hamilton, S. E., Lee, S. Y., Lucas, R., Primavera, J., Rajkaran, A., & Shi, S. (2019). The state of the world's mangrove forests. Annual Review of Environment and Resources, 44, 89–115.

Goldberg, L., Lagomasino, D., Thomas, N., & Fatoyinbo, T. (2020). Global declines in human-driven mangrove loss. Global Change Biology, 26(10), 5844–5855.

Intergovernmental Panel on Climate Change. (2023). Climate change 2023: Synthesis report. IPCC.

Kristensen, E., Bouillon, S., Dittmar, T., & Marchand, C. (2008). Organic carbon dynamics in mangrove ecosystems. Aquatic Botany, 89(2), 201–219.

Lehmann, J., & Kleber, M. (2015). The contentious nature of soil organic matter. Nature, 528, 60–68.

Lovelock, C. E., & Reef, R. (2020). Variable impacts of climate change on blue carbon. One Earth, 3(2), 195–211.

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., ... Duarte, C. M. (2021). The future of blue carbon science. Nature Communications, 12, 3998.

Murdiyarso, D., Purbopuspito, J., Kauffman, J. B., Warren, M. W., Sasmito, S. D., Donato, D. C., Manuri, S., Krisnawati, H., Taberima, S., & Kurnianto, S. (2015). The potential of Indonesian mangrove forests for global climate change mitigation. Nature Climate Change, 5, 1089–1092.

NASA. (2025). Sea level change and coastal climate indicators. National Aeronautics and Space Administration.

NOAA. (2025). Coastal inundation and sea-level rise indicators. National Oceanic and Atmospheric Administration.

Primavera, J. H., & Esteban, J. M. A. (2008). A review of mangrove rehabilitation in the Philippines. Wetlands Ecology and Management, 16, 345–358.

Rogers, K., Kelleway, J. J., Saintilan, N., Megonigal, J. P., Adams, J. B., Holmquist, J. R., Lu, M., Schile-Beers, L., Zawadzki, A., Mazumder, D., & Woodroffe, C. D. (2019). Wetland carbon storage controlled by millennial-scale variation in relative sea-level rise. Nature, 567, 91–95.

Sanderman, J., Hengl, T., Fiske, G., Solvik, K., Adame, M. F., Benson, L., Bukoski, J. J., Carnell, P., Cifuentes-Jara, M., Donato, D., Duncan, C., Eid, E. M., Ermgassen, P. Z., Lewis, C. J. E., Macreadie, P. I., Glass, L., Gress, S., Jardine, S. L., Jones, T. G., ... Landis, E. (2018). A global map of mangrove forest soil carbon at 30 m spatial resolution. Environmental Research Letters, 13(5), 055002.

Taillardat, P., Friess, D. A., & Lupascu, M. (2018). Mangrove blue carbon strategies for climate change mitigation are most effective at the national scale. Biology Letters, 14(10), 20180251.

UNEP. (2023). Into the blue: Securing a sustainable future for mangroves. United Nations Environment Programme.

UNEP. (2025). Global environment outlook: Coastal ecosystems and climate resilience. United Nations Environment Programme.

Worthington, T. A., zu Ermgassen, P. S. E., Friess, D. A., Krauss, K. W., Lovelock, C. E., Thorley, J., Tingey, R., Woodroffe, C. D., Bunting, P., Cormier, N., Lagomasino, D., Lucas, R., Murray, N. J., Sutherland, W. J., & Spalding, M. (2020). A global biophysical typology of mangroves and its relevance for ecosystem structure and deforestation. Scientific Reports, 10, 14652.

World Meteorological Organization. (2025). State of the global climate 2024. WMO.