

**CLIMATE SMART ACTIONS (CSA) AQUACULTURE, AGROFORESTRY
AND RESOURCES MANAGEMENT**

GLOBAL ISSUES & LOCAL PERSPECTIVES

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Global Issues & Local Perspectives

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Preface

This book adopts an exegetical approach as well as a pedagogic model, making it attractive agriculture and environmental economics teachers, professional practitioners and scholars. It eschews pedantry and lays bars the issues in such clarity that conduces to learning. The book elaborates on contemporaneous **Climate smart actions (CSA) aquaculture, agroforestry and resources management** issues of global significance and at the same time, is mindful of local or national perspectives making it appealing both to international and national interests. The book explores the ways in which **Climate smart actions (CSA) aquaculture, agroforestry and resources management** issues are and should be presented to increase the public's stock of knowledge, increase awareness about burning issues and empower the scholars and public to engage in the participatory dialogue **Climate smart actions (CSA) aquaculture, agroforestry and resources management** necessary in policy making process that will stimulate increase in food production and environmental sustainability. **Climate smart actions (CSA) aquaculture, agroforestry and resources management : *Global Issues & Local Perspectives*** is organized in three parts. Part One deals with The Concept of **Climate smart actions (CSA)**, Part Two is concerned with The Concept of **aquaculture**, and Part Three deals with the Concept of **agroforestry and resources management**

Eteyen Nyong; March 2026

Chapter 11:

**Blue Carbon and Aquaculture: The Role of Coastal and Inland
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1.0 Introduction

Aquaculture is increasingly recognized not only as a vital source of food, nutrition, income, and employment but also as an emerging contributor to natural climate solutions (El Salous *et al.*, 2025). As countries seek strategies to reduce greenhouse gas (GHG) emissions across global food systems, aquaculture offers a relatively low-carbon alternative to capture fisheries and land-based livestock production. Traditional blue carbon ecosystems such as mangroves, seagrasses, and saltmarshes have long been acknowledged for their exceptional carbon sequestration and long-term carbon burial capacities (Choudhary *et al.*, 2024; Chen *et al.*, 2025a). These ecosystems function as highly efficient carbon sinks, storing carbon in plant biomass and sediment layers for centuries while simultaneously providing coastal protection and supporting biodiversity.

Recent scientific discourse, however, expands the blue carbon framework to include aquaculture-based systems. These include seaweed and shellfish aquaculture, as well as inland aquaculture ponds, which are increasingly recognized for their potential contributions to carbon capture and sequestration (Castilla-Gavilán *et al.*, 2024; Zhang *et al.*, 2024; Chen *et al.*, 2025b). Seaweed farms exhibit rapid biomass growth rates, capturing substantial volumes of CO₂ through photosynthesis, with harvested biomass offering opportunities for long-term carbon storage or conversion into climate-beneficial products. Shellfish aquaculture enhances carbon regulation indirectly by filtering particulate organic matter, improving water clarity, and facilitating sediment carbon burial (Jones *et al.*, 2022). Similarly, inland aquaculture ponds once viewed primarily as methane emitters but now being re-evaluated, as improved pond management practices can reduce GHG emissions while simultaneously enhancing sediment carbon storage.

Given the growing global demand for low-carbon, nature-based, and climate-resilient food production, integrating aquaculture with blue carbon ecosystems represents a compelling pathway for climate mitigation. Such integration enhances not only carbon sequestration potential but also critical ecosystem services, including habitat creation, water purification, shoreline stabilization, nutrient cycling, and livelihood diversification for coastal and inland communities.

This chapter provides a comprehensive assessment of the mechanisms, carbon sequestration potentials, and policy and governance implications of blue carbon within aquaculture systems. It evaluates the biophysical processes that support carbon capture in aquaculture ponds, mangrove – aquaculture integrated systems, seaweed and macroalgal cultivation, and shellfish farming. In addition, it examines emerging climate-smart innovations, carbon accounting methodologies, monitoring frameworks, and financing mechanisms such as blue carbon credits and payment for ecosystem services that are essential for unlocking aquaculture’s climate mitigation value. The chapter also highlights key challenges, research gaps, and policy

opportunities for mainstreaming aquaculture within global climate action agendas, especially under the Paris Agreement and Sustainable Development Goals.

The primary aim of this chapter is to critically analyze the role of aquaculture systems in blue carbon sequestration and evaluate their potential contributions to global climate mitigation strategies.

1.1 The Specific Objectives are:

- a) To examine the ecological and biophysical mechanisms through which different aquaculture systems ponds, seaweed farms, shellfish beds, and mangrove-integrated aquaculture capture and store carbon.
- b) To assess the carbon sequestration potential of coastal and inland aquaculture systems based on recent global evidence.
- c) To explore climate-smart innovations and management practices that enhance carbon storage while improving aquaculture productivity.
- d) To evaluate policy, governance, and institutional frameworks supporting blue carbon integration within the aquaculture sector at global and national levels.
- e) To identify challenges, research gaps, and opportunities for leveraging aquaculture - based blue carbon systems within international climate mitigation mechanisms, including carbon markets and nature-based solution frameworks.

2.0 Conceptual Foundations of Blue Carbon

2.1 Blue Carbon: Definition and Ecological Basis

Blue carbon refers to the carbon captured, stored, and sequestered within coastal, marine, and connected aquatic ecosystems (Choudhary *et al.*, 2024). These systems are among the most efficient natural carbon sinks on Earth due to their ability to store carbon not only in living biomass but also deep within sediments, where carbon can remain buried for centuries to millennia (White *et al.*, 2025). Unlike terrestrial forests, blue carbon ecosystems continuously trap organic carbon in water-saturated, anaerobic (oxygen-poor) conditions, significantly slowing decomposition and enhancing long-term carbon retention (Jahan & Islam, 2025).

Blue carbon ecosystems store carbon in multiple interconnected compartments (Table 1), with soils and sediments serving as the largest and most stable long-term sinks. Integrating aquaculture can enhance storage through biomass accumulation, sediment enrichment, and offshore carbon export, making these systems essential tools for climate mitigation.

Table 1: Ecological Compartments of Blue Carbon Storage

CLIMATE SMART ACTIONS (CSA) AQUACULTURE, AGROFORESTRY AND RESOURCES MANAGEMENT(GLOBAL ISSUES & LOCAL PERSPECTIVES)

Ecological Compartment	Description	Carbon Storage Mechanism	Ecosystems	Relative Storage Capacity
Above - ground Biomass	Living plant material above the soil or sediment surface	Carbon fixed via photosynthesis and stored in stems, leaves, and branches	Mangrove trees, saltmarsh grasses, seagrasses	Moderate: biomass turnover is relatively fast
Below - ground Biomass	Roots and rhizomes beneath the substrate	Long-lived root structures store carbon for decades; also trap sediments rich in organic carbon	Mangrove roots, seagrass rhizomes, saltmarsh root mats	High: dense root systems slow decomposition
Soils and Sediments	Accumulated organic material buried in anaerobic sediments	Organic carbon burial under low oxygen conditions slows decomposition, enabling centuries-long storage	Mangrove muds, seagrass and saltmarsh sediments, aquaculture pond bottoms	Very High: largest blue carbon reservoir
Water Column Organic Matter	Suspended or dissolved organic carbon in the water	Phytoplankton and detritus-derived carbon become trapped in sediments or exported offshore	Estuaries, lagoons, aquaculture ponds	Low – Moderate: depends on hydrodynamics
Biomass of Cultured Species	Carbon stored in tissues and shells of farmed organisms	Seaweeds absorb CO ₂ through photosynthesis; shellfish incorporate carbonates into shells	Seaweed farms, mussel beds, oyster farms	Moderate: enhanced when biomass is harvested into long-lived products
Exported Carbon to Deep Sea	Carbon transported away from coastal systems into deeper waters	Detached seaweed and organic matter sink to deep-sea sediments where decomposition is slow	Offshore export from kelp farms, drifting seagrass detritus	High (when burial occurs) – potentially long-term sequestration

These ecosystems also provide co-benefits such as shoreline protection, biodiversity conservation, nutrient cycling, and support for fisheries.

2.2 Blue Carbon Ecosystems and Their Characteristics

Mangroves store the highest blue carbon, primarily in deep, anaerobic soils. Aquaculture systems (seaweed, shellfish, ponds) are emerging blue carbon contributors with rising global interest. A combination of natural ecosystems (Table 2) and sustainable aquaculture offers powerful pathways for climate mitigation.

Table 2: Blue Carbon Ecosystems and Their Characteristics

CLIMATE SMART ACTIONS (CSA) AQUACULTURE, AGROFORESTRY AND RESOURCES MANAGEMENT(GLOBAL ISSUES & LOCAL PERSPECTIVES)

Ecosystem	Characteristics	Carbon Storage Capacity	Functions
<p>A) Mangroves</p> <ul style="list-style-type: none"> • Nursery habitat for fish • Sediment trapping • High carbon burial in anaerobic soils 	<p>Coastal forests with salt-tolerant trees; dense root systems; thrive in intertidal zones</p> <p>Niger Delta (Nigeria), Rufiji Delta (Tanzania), Gazi Bay (Kenya)</p>	<p>Very High – up to 1,000 t C ha⁻¹ stored in soils and biomass</p>	<ul style="list-style-type: none"> • Shoreline protection
<p>B) Seagrasses</p> <ul style="list-style-type: none"> • Improve water clarity • Provide habitat for juvenile fish and invertebrates 	<p>Submerged flowering plants forming underwater meadows; slow biomass turnover</p> <p>Mediterranean seagrass meadows; Coastal South Africa</p>	<p>High – long-term carbon burial in sediments</p>	<ul style="list-style-type: none"> • Stabilize sediments
<p>C) Saltmarshes</p> <ul style="list-style-type: none"> • Nutrient filtration • Habitat for birds and estuarine species 	<p>Intertidal grassy wetlands dominated by halophytic vegetation; high organic soils</p> <p>Atlantic coast marshes; St. Lucia Estuary (South Africa)</p>	<p>High – extensive soil organic carbon accumulation</p>	<ul style="list-style-type: none"> • Flood buffering
<p>D) Seaweed / Macroalgal Farms</p> <ul style="list-style-type: none"> • Habitat creation • Climate-friendly biomass production 	<p>Cultivated macroalgae with rapid growth rates; no soil required</p> <p>Kappaphycus farms (Tanzania), Saccharina farms (China)</p>	<p>Moderate – High – large biomass production; some exported to deep sea</p>	<ul style="list-style-type: none"> • Nutrient absorption
<p>E) Shellfish Beds (Oysters, Mussels, Clams)</p> <ul style="list-style-type: none"> • Habitat complexity • Sediment stabilization 	<p>Dense filter-feeding communities; carbonate shell formation</p> <p>Oyster beds in Gambia; Mussel farms in Morocco</p>	<p>Moderate – carbon stored in shells (CaCO₃)</p>	<ul style="list-style-type: none"> • Water filtration
<p>F) Aquaculture Ponds (Freshwater & Brackish)</p> <ul style="list-style-type: none"> • Controlled habitat for fish farming 	<p>Man-made water bodies with high organic matter and sediment deposition</p>	<p>Moderate – High – carbon burial in pond sediments</p>	<ul style="list-style-type: none"> • Nutrient recycling

Ecosystem	Characteristics	Carbon Storage Capacity	Functions
<ul style="list-style-type: none"> Potential methane reduction through improved management 	Catfish ponds (Nigeria), Carp ponds (Kenya)		
G) Tidal Flats / Mudflats	Soft-sediment intertidal zones exposed at low tide	Low – Moderate – carbon stored mainly in sediments	<ul style="list-style-type: none"> Feeding grounds for fish and birds
<ul style="list-style-type: none"> Sediment deposition Early successional habitat for mangrove expansion 	East African mudflats; Banc d’Arguin (Mauritania)		

2.3 Carbon Storage Processes in Blue Carbon Ecosystems

Blue carbon ecosystems including mangroves, seagrasses, saltmarshes, seaweed farms, shellfish beds, and aquaculture ponds store carbon through multiple ecological pathways. Each pathway contributes differently to carbon capture, retention, and long-term sequestration (Table 3). Understanding these processes is essential for quantifying the climate mitigation value of aquaculture - integrated blue carbon systems.

Table 3: Characteristics of Carbon Storage Processes in Blue Carbon and Aquaculture Systems

Process	Characteristics	Ecosystems	Carbon Stability	Examples
Biomass Carbon	CO ₂ captured in living tissues of plants and animals; rapid uptake	Mangroves, Seagrasses, Seaweed farms, Shellfish	Short – medium term; long - term if biomass buried or processed	Mangrove wood, kelp biomass, shellfish soft tissue
Sediment Carbon	Organic matter buried in soils/sediments; largest carbon pool in coastal ecosystems	Mangrove soils, Seagrass sediments, Saltmarsh soils, Aquaculture-pond bottoms	Long - term (decades – centuries)	Mangrove peat soils, pond sludge carbon
Water-Column Carbon	Dissolved/particulate organic carbon suspended in water; influenced by plankton and seaweed	Seaweed farms, Coastal lagoons, Aquaculture ponds	Short-term; may lead to sediment deposition or export	Phytoplankton productivity, DOC export
Biogenic Carbonates (CaCO ₃)	Carbon stored in shells and exoskeletons; mineralized carbon	Shellfish beds (oysters, clams, mussels), Coral reefs	Long - term if shells accumulate in sediments	Oyster shells, mussel beds, clam deposits

3.0 Carbon Sequestration Pathways in Aquaculture Systems

Aquaculture plays an increasingly important role in global climate mitigation by acting as both a carbon sink and a substitute for emission-intensive production systems (Maulu *et al.*, 2021). According to Cortes

et al., (2025), Climate-smart aquaculture integrates ecological processes, sustainable production practices, and innovative technologies that help reduce greenhouse gas (GHG) emissions. Aquaculture enhances blue carbon storage through biomass growth, sediment burial, shell formation, nutrient assimilation, ecosystem restoration, and climate-smart management practices (Choudhary *et al.*, 2024). When integrated with natural habitats such as mangroves and seagrasses, aquaculture becomes a powerful nature-based climate solution (Ashrafuzzaman, 2025). The following mechanisms highlight the pathways (Table 4) by which Carbon sequestration takes place in aquaculture systems:

Table 4: Pathways for Blue Carbon Sequestration in Aquaculture Systems

Carbon Sequestration Pathway	Description	Aquaculture Types	Carbon Sequestration Potential
1. Biomass Carbon Accumulation	CO ₂ absorbed during growth is stored in tissues of cultured organisms.	Seaweed farms, shellfish farms, finfish aquaculture	Moderate–High (fast-growing seaweeds store 1–10 t C ha ⁻¹ yr ⁻¹)
2. Sediment Carbon Burial	Organic particles (feces, uneaten feed, dead algae) settle and are buried under low-oxygen conditions.	Ponds, shellfish beds, mangrove – aquaculture systems	High (long-term burial in anaerobic sediments)
3. Deep-Sea Carbon Export	Detached macroalgal detritus sinks to deep waters where decomposition is slow.	Offshore drift from seaweed or kelp farms	High (potential long-term sequestration when burial occurs)
4. Biogenic Carbonate Formation	Shellfish incorporate carbon into CaCO ₃ shells that can persist in sediments for decades.	Oyster, clam, mussel aquaculture	Moderate (carbonate storage varies across species)
5. Enhanced Primary Productivity	Nutrient-rich water boosts phytoplankton & microalgae growth, increasing CO ₂ uptake.	Fertilized ponds, IMTA (integrated multi-trophic aquaculture)	Moderate (dependent on nutrient levels & light availability)
6. Mangrove – Aquaculture Integration (Silvofisheries)	Mangroves planted around ponds capture large amounts of carbon in biomass and soils.	Shrimp – mangrove systems, tidal pond systems	Very High (mangrove forests store up to 1,000 t C ha ⁻¹)
7. Nutrient Uptake & Water Purification	Seaweeds and filter feeders remove nutrients, enabling healthier ecosystems that store more carbon.	Seaweed – shellfish co-culture, IMTA	Moderate (improves ecosystem carbon efficiency)
8. Reduced Methane Emissions (Improved Pond Management)	Aeration, optimized feeding, and sediment removal reduce CH ₄ emissions in ponds.	Catfish, tilapia, carp ponds	Indirect but significant (reduces greenhouse gas footprint)

Carbon Sequestration Pathway	Description	Aquaculture Types	Carbon Sequestration Potential
9. Long-Lived Product Formation	Harvested seaweed or shells used in durable products (biochar, bioplastics, construction materials).	Seaweed biorefineries, shell recycling programs	High (carbon remains stored for long durations)
10. Substitution Effects	Seaweed-based feeds replace carbon-intensive livestock feeds, reducing emissions elsewhere.	Asparagopsis feed supplements	Indirect but large potential for methane reduction in livestock

*** t C ha⁻¹ yr⁻¹ - tonnes of carbon per hectare per year

4.0 Coastal Aquaculture Systems as Blue Carbon Solutions

Coastal aquaculture systems have emerged as vital components of nature-based climate solutions due to their capacity to store carbon, enhance ecosystem functioning, and support sustainable food production. When designed using ecological principles, these systems sequester carbon through biomass accumulation, sediment deposition, and biogenic carbonate formation (Das *et al.*, 2025). This section discusses the major types of coastal aquaculture that contribute meaningfully to blue carbon pathways.

4.1 Mangrove – Aquaculture Integration (Silvofisheries)

4.1.1 Ecological Principles Mangrove – Aquaculture Integration (Silvofisheries)

Silvofisheries combine mangrove conservation with fish or shrimp farming. Rather than clearing mangrove forests for ponds, farmers retain or replant mangroves within or around aquaculture systems (Suyono, 2025). Ecological principles include:

- i. Maintaining hydrological connectivity, allowing natural tidal flushing and nutrient exchange.
- ii. Enhancing habitat complexity, improving shelter and nursery grounds for juvenile fishes and crustaceans.
- iii. Promoting sediment accretion, which increases carbon storage potential.

4.1.2 Carbon Stocks and Benefits of Mangrove – Aquaculture Integration (Silvofisheries)

- i. Mangroves store up to 1,000 t C ha⁻¹ in above- and below-ground biomass and sediments.
- ii. Integration increases soil carbon burial due to enhanced litterfall and organic matter accumulation.
- iii. Provides coastal protection, reducing erosion and buffering storm surges.
- iv. Improves water quality, facilitating healthier aquaculture production.

4.1.3 Case Studies of Mangrove – Aquaculture Integration (Silvofisheries)

- i. Indonesia & Bangladesh: Silvofisheries have increased shrimp yields while restoring mangrove cover (Ahmed *et al.*, 2023).

- ii. Nigeria (Niger Delta): Community-based mangrove replanting linked to fishponds has boosted local fisheries and carbon stocks (Aransiola *et al.*, 2024).
- iii. Vietnam: Integrated shrimp–mangrove systems certified under organic and carbon-sensitive standards (Hua *et al.*, 2025).

4.2 Seaweed and Macroalgal Farming

4.2.1 High Biomass Productivity of Seaweed and Macroalgal Farming

Seaweed cultivation is one of the fastest-growing aquaculture sectors. Table 5 below shows several species such as *Kappaphycus*, *Saccharina*, and *Gracilaria* can achieve:

- Biomass yields of 20 – 40 t dry weight ha⁻¹ yr⁻¹
- Carbon sequestration rates of 1 – 10 t C ha⁻¹ yr⁻¹ depending on species and location

4.2.2 Carbon Removal Pathways of Seaweed and Macroalgal Farming

Seaweed functions as an effective biological carbon pump through:

- Photosynthetic uptake of CO₂, converting it into biomass
- Export of detritus to deep waters where carbon is stored long-term
- Conversion into long-lived products, such as bioplastics and soil conditioners
- Displacement effects, where seaweed is used in livestock feed, reducing methane emissions

Table 5: Seaweed Species, Carbon Sequestration Potential, and Co-Benefits

Seaweed Species	Co-Benefits	Applications
<i>Kappaphycus alvarezii</i>	Rapid biomass growth; coastal habitat; nutrient absorption	Carrageenan production; livestock feed additive
<i>Saccharina japonica</i>	High carbon fixation; biofiltering; supports marine biodiversity	Human food, biofuel, bioplastics
<i>Sargassum</i> spp.	Provides habitat; enhances sedimentation; nitrogen removal	Coastal restoration, fertilizer, animal feed
<i>Gracilaria</i> spp.	Nutrient uptake; biofiltering; co-culture with shellfish	Agar production; integrated multi-trophic aquaculture (IMTA)
<i>Ulva</i> spp. (sea lettuce)	Fast growth; nutrient remediation; carbon storage in biomass	Food, feed, fertilizer, bioenergy
<i>Asparagopsis</i> spp.	Methane-reducing feed additive; nutrient absorption	Livestock feed, carbon mitigation in agriculture

4.3 Shellfish Aquaculture

4.3.1 Carbonate Sequestration of Shellfish Aquaculture

Shellfish such as oysters, clams, mussels, and scallops sequester carbon (Table 6) through:

- i. Biogenic calcium carbonate (CaCO₃) formation, which constitutes up to 95% of shell weight (Bellei *et al.*, 2023)

- ii. Long-term carbon storage if shells are buried, reused for reef restoration, or incorporated into construction materials (Sea *et al.*, 2022).

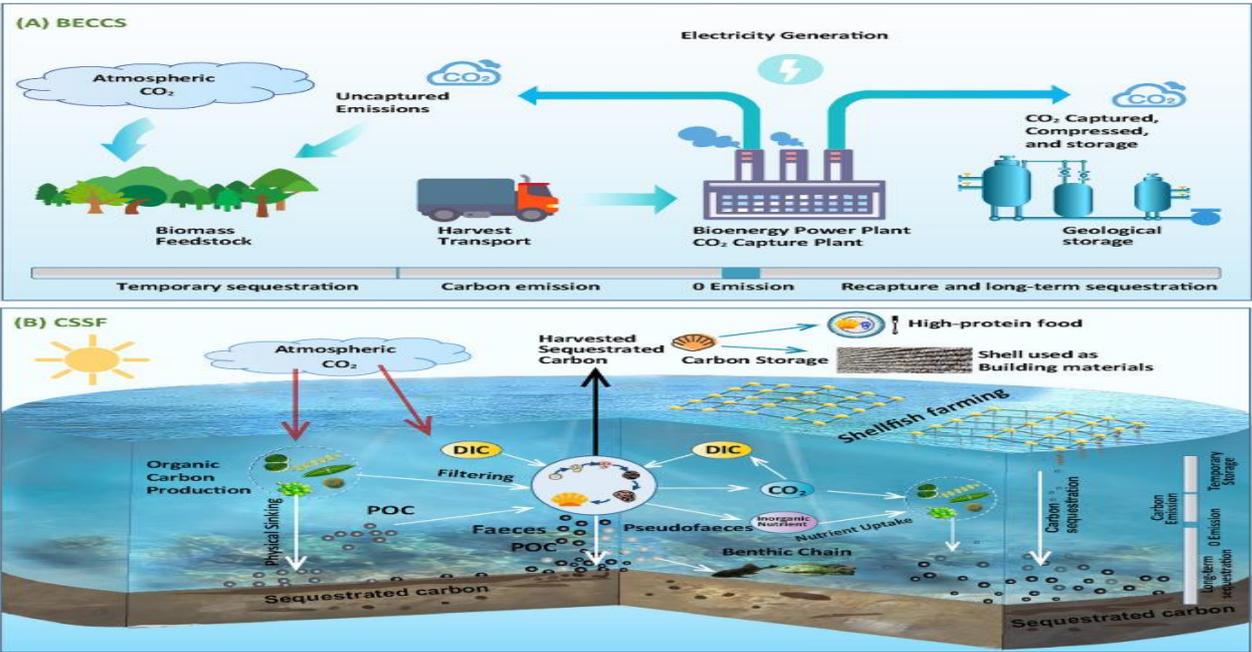
Table 6: Shellfish Species, Carbon Sequestration Potential, and Co-Benefits

Shellfish Species	Carbon Sequestration Mechanism	Estimated Carbon Storage / Notes	Co-Benefits
Oysters (<i>Crassostrea virginica</i> , <i>Crassostrea gasar</i>)	Carbonate shell formation; tissue carbon; sediment deposition	Shells ~ 95% CaCO ₃ ; organic carbon in tissues; contributes to long-term sediment carbon	Water filtration, habitat creation, shoreline protection, biodiversity support
Clams (<i>Ruditapes spp.</i> , <i>Meretrix spp.</i>)	Shell carbonate storage; sediment accumulation	Moderate carbonate content; carbon stored in shells and sediments	Nutrient removal, sediment stabilization, supporting benthic biodiversity
Mussels (<i>Mytilus spp.</i>)	Shell carbonate deposition; organic carbon in tissues	Shell biomass stores inorganic carbon; detritus contributes to sediment carbon	Water filtration, nutrient cycling, habitat for epibenthic species
Mixed Shellfish Reefs / Co-culture (Oysters + Mussels)	Combined carbonate and organic carbon storage; enhanced sedimentation	Higher cumulative carbon sequestration due to structural complexity	Improved water quality, sediment stabilization, biodiversity, coastal protection

4.3.2 Water Filtration and Sediment Stabilization

- i. A single oyster can filter 20 – 50 liters of water per day, removing particulates and organic carbon.
- ii. Filtration enhances water clarity, promoting seagrass growth and increasing overall blue carbon potential.
- iii. Shellfish beds stabilize sediments, reducing resuspension of stored carbon and creating positive feedback loops for carbon retention. Figure 1 below illustrates the Carbon sequestration via shellfish farming.

CLIMATE SMART ACTIONS (CSA) AQUACULTURE, AGROFORESTRY AND RESOURCES MANAGEMENT(GLOBAL ISSUES & LOCAL PERSPECTIVES)



** BECCS - bioenergy with carbon capture and storage; CSSF - carbon sequestration via bivalve shellfish farming

Figure 1: Carbon sequestration via shellfish farming
Source: Feng *et al.*, 2023

5.0 Inland Aquaculture Ponds and Carbon Dynamics

Inland aquaculture ponds play a significant but understudied role in global carbon cycling. These ponds whether used for fish, shrimp, or integrated agri-aquaculture systems serve simultaneously as sources and sinks of greenhouse gases (GHGs), particularly methane (CH₄) and carbon dioxide (CO₂), while also accumulating organic carbon in sediments (Deng *et al.*, 2024). Understanding their carbon dynamics is essential for improving environmental sustainability, optimizing production and exploring opportunities for carbon credits.

5.1 Sediment Organic Carbon Accumulation

Sediments in aquaculture ponds serve as long-term repositories for organic matter derived from feed residues, fish feces, dead biomass, and autochthonous primary production (mainly algae and macrophytes). Depending on pond management, a substantial proportion of this organic matter is buried, turning ponds into carbon sinks. The factors influencing organic Carbon accumulation is shown in table 7.

Table 7: Factors Influencing Organic Carbon Burial in Inland Aquaculture Ponds

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Factor	Effect on Carbon Accumulation	Mechanism
Feeding intensity	↑ organic carbon	Excessive feeding increases uneaten feed and fecal deposition, which settles into sediments as labile organic matter.
Feed type and quality	↑ or ↓	High-quality, highly digestible feeds reduce waste; low-quality feeds increase organic deposition due to poor digestibility.
Feed conversion ratio (FCR)	↑ carbon loading with high FCR	Inefficient feed utilization results in greater waste production and higher sediment organic matter.
Fertilization (organic and inorganic)	↑ carbon deposition	Fertilizers stimulate phytoplankton blooms; dead biomass settles, contributing autochthonous carbon to sediments.
Primary productivity level	↑ carbon sinking	High algal or macrophyte productivity increases biological carbon capture and sedimentation of particulate organic matter.
Pond age	↑ burial over time	Older ponds accumulate thicker sediment layers and store carbon over long periods due to continuous deposition.
Sediment characteristics (texture, mineralogy)	↑ retention in fine sediments	Clay/silt particles bind organic matter more effectively; sandy substrates promote faster decomposition and less carbon storage.
Stocking density	↑ or ↓ depending on species	High densities increase organic inputs (feces, feed waste), but benthic-disturbing species (e.g., catfish, carp) resuspend sediments, enhancing decomposition and reducing burial.
Fish species behavior (bioturbation)	↓ sequestration if disturbance is high	Sediment mixing exposes carbon to oxygen, accelerating decomposition and reducing long-term storage.
Water exchange / flushing rate	↓ retention	Frequent water exchange removes suspended and dissolved carbon before it settles into sediments.
Hydrology and water level stability	↑ burial with stable water levels	Stable, low-flow conditions favor deposition of particulate carbon; fluctuating water levels resuspend sediments.
Aeration practices	↓ long-term burial but ↑ carbon mineralization	Aeration oxygenates sediments, enhancing decomposition and reducing organic matter buildup; however, it may reduce methane emissions.
Temperature	↑ decomposition in warmer climates	Warm temperatures stimulate microbial activity, accelerating breakdown of organic matter and reducing carbon burial efficiency.
pH and redox potential	↑ retention under low redox	Low redox conditions (anoxia) slow decomposition, promoting carbon preservation; high pH can enhance chemical stabilization of organic matter.
Sludge removal frequency	↓ long-term carbon storage	Removing sediment sludge decreases carbon burial but improves water quality and reduces methane production.

Factor	Effect on Carbon Accumulation	Mechanism
Macrophyte presence	↑ organic matter input	Plant litter contributes additional carbon; root systems can stabilize sediments and trap particulates.
Seasonal variations	↑ or ↓ depending on rainfall and temperature	Rainy seasons may increase runoff-derived carbon but also cause flushing; dry seasons promote sediment stability and burial.
External inputs (runoff, erosion)	↑ allochthonous carbon	Runoff introduces soil-derived carbon and organic matter into ponds, adding to sediment accumulation.
Pond management intensity (traditional vs. intensive)	↑ in intensive systems	Intensive systems produce more feed waste and fecal matter, leading to higher organic loading and sediment carbon buildup.

** ↑ - increase; ↓ - decrease

5.2 Methane Mitigation Strategies

Methane emissions from aquaculture ponds (Figure 2) arise mainly from anaerobic decomposition of accumulated organic matter in sediments (Malyan *et al.*, 2022). Reducing methane not only lowers GHG emissions but can improve oxygen levels, enhance fish health, and increase productivity (Jorge *et al.*, 2025).

a) Aeration

- Increases dissolved oxygen (DO) in the water column and, secondarily, in the upper sediment layers.
- Suppresses methanogenesis and promotes complete oxidation of organic matter.
- Paddle wheel aerators can also enhance sediment resuspension, decreasing anaerobic zones.
- Aeration helps create oxidizing micro-environments unfavorable for methane-producing archaea.

b) Feeding Optimization

- Reducing overfeeding minimizes organic loading.
- Switching to high-quality feeds with better digestibility reduces fecal waste.
- Improving FCR through:
 - Scheduled feeding
 - Automated feeders
 - Probiotics and digestive enhancers
- Lower organic loading equals less substrate for methanogenesis.

c) Liming

- Application of agricultural lime (CaCO₃) increases pH and reduces sediment acidity.
- Helps maintain favorable conditions for aerobic microbes.
- Improves sediment redox potential, which discourages methane formation.

d) Sludge Removal and Sediment Management

- Periodic removal of bottom sludge reduces organic matter accumulation.
- Draining and sun-drying during pond preparation:
 - Oxidizes organic residues
 - Disrupts anaerobic decomposers
 - Enhances mineralization of stored carbon
- Improves sediment quality and reduces GHG hotspots.

e) Integrated Systems

- Integration with plants (e.g., rice–fish, lettuce rafts) enhances carbon capture through photosynthesis.
- Macrophytes can oxygenate upper sediment layers via root exudation.

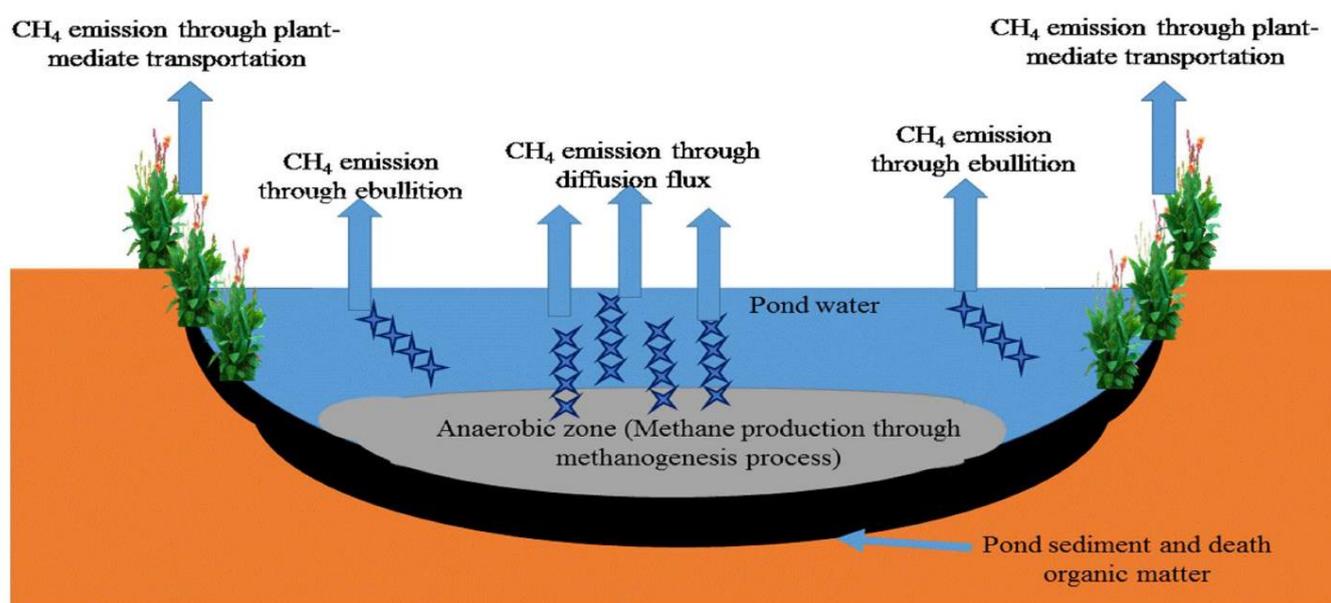


Figure 2: Methane sources and mitigation practices in aquaculture ponds

Source: Malyan *et al.*, 2022

5.3 Potential for Carbon Credits

As governments and industries seek low-carbon solutions, aquaculture ponds show promise for participation in carbon markets, especially through carbon sequestration in sediments and methane reduction technologies.

Inland aquaculture ponds are important components of the global carbon cycle. They accumulate organic carbon through sediment deposition, emit methane via anaerobic decomposition, and offer viable opportunities (table 8) for climate mitigation. Effective management including optimized feeding, aeration, liming, and sludge removal can reduce GHG emissions while enhancing productivity. With improved

methodologies and validation frameworks, aquaculture ponds may soon be integrated into carbon credit schemes, contributing to both sustainable food production and climate resilience.

Table 8: Opportunities for Carbon Credit Generation in Inland Aquaculture

Aspect	Opportunity
Sediment carbon sequestration	High carbon burial rates in pond sediments; potential for long-term carbon storage if undisturbed.
Organic carbon inputs	High organic matter loading from feed, feces, and primary productivity which increases carbon deposition.
Methane (CH ₄) reduction	Mitigation via aeration, optimized feeding, liming, probiotics, and sludge management reduces emissions.
Use of improved technologies	Adoption of recirculation systems, solar aerators, and precision feeding can reduce GHGs and be creditable under activity-based carbon schemes.
Blue carbon integration	Expanding the concept of blue carbon to include inland ponds increases the recognized carbon pool and eligibility.
Co-benefits for climate-smart aquaculture	Improved water quality, reduced eutrophication, and enhanced fish health serve as additional incentives for adopting mitigation practices.
Market access through voluntary carbon markets (VCMs)	Farmers can monetize climate-friendly practices and diversify income by selling voluntary carbon credits.
Emerging digital MRV technologies (Monitoring, Reporting, Verification)	Remote sensing, IoT-based sensors, and modeling tools can help automate carbon accounting in ponds.
Integration with nature-based solutions (NBS)	Combining ponds with wetlands, mangroves, or agroforestry enhances sequestration and may qualify for hybrid carbon projects.
Government policy incentives	Expansion of national carbon registries and climate-smart agriculture policies may create new opportunities for aquaculture inclusion.
Cluster or cooperative-based carbon projects	Farmer groups can aggregate ponds to reduce costs and increase carbon credit volumes for project viability.

6.0 Measurement, Reporting, and Verification (MRV) in Blue Carbon Aquaculture

Measurement, Reporting, and Verification (MRV) systems are essential for ensuring that carbon sequestration and emission reductions in aquaculture systems are scientifically credible, transparent, and eligible for carbon markets (Abu El Haija & Santos, 2024). Although blue carbon MRV frameworks have been well developed for mangroves, seagrasses, and salt marshes, their application to inland aquaculture ponds and coastal aquaculture systems (e.g., seaweed farming, silvofisheries, shellfish aquaculture) is emerging. Effective MRV enables robust carbon accounting, supports climate-smart aquaculture, and facilitates access to voluntary carbon markets (Ajayi *et al.*, 2025).

6.1 Carbon Accounting Methods

Accurate carbon accounting in aquaculture requires integrating biological, chemical, and physical measurements (Li *et al.*, 2025). The three core components include the following:

a) **Biomass Estimation:** Biomass estimation quantifies the amount of carbon stored in living organisms within the aquaculture system. This includes both cultured species and associated biota such as plankton and benthic organisms.

➤ **Approaches of Biomass Estimation:**

- i. Direct biomass measurement: Harvesting representative samples (e.g., seaweed, fish, bivalves) and determining dry weight and carbon content (commonly ~30–40% of dry weight for seaweeds).
- ii. Allometric models: Predict biomass from body length, shell size, or thallus length using established allometric equations.
- iii. Growth rate monitoring: Regular measurement of growth increments (daily/weekly) helps estimate net primary production (particularly useful for seaweed and macroalgae farms).
- iv. Photosynthetic production estimates: For seaweed systems, carbon assimilation can be calculated using net photosynthesis rates combined with areal coverage.

➤ **Applications of Biomass Estimation Across Aquaculture Types:**

- i. Seaweed farms: Major carbon sequestration potential through biomass harvest.
- ii. Shellfish systems: Carbon stored in shells (aragonite/calcite) and tissue.
- iii. Fish ponds: Limited biomass storage, but contributes indirectly via sedimentation of organic matter.

b) **Sediment Sampling:** Sediments serve as long-term carbon sinks, especially in ponds and silvofisheries. Quantifying sediment carbon is essential for estimating sequestration.

➤ **Steps in Sediment Carbon Measurement:**

- i. Core collection: Sediment cores taken using corers (e.g., Kajak, gravity, push cores) to depths of 20 – 100 cm depending on pond age.
- ii. Layer stratification: Cores are sliced into layers (e.g., every 2–5 cm) to determine carbon deposition over time.
- iii. Laboratory analysis:
 - Loss-on-ignition (LOI) for organic matter content
 - Elemental analysis (CHN analyzers) to measure organic carbon percentage
 - Bulk density determination to calculate carbon mass per unit area
- iv. Carbon accumulation rate calculation: Based on sediment depth, age of pond, and carbon concentration.

➤ **Importance of Sediment Carbon Measurement:**

- i. Sediments store 70 – 90% of total carbon buried in aquaculture ponds.
- ii. Essential for determining long-term (>20 years) sequestration potential.
- iii. Critical for carbon credit schemes focusing on permanence.

- c) **Carbon Flux Modelling:** Carbon flux modelling quantifies exchanges of carbon between the pond and the atmosphere, including CO₂ and CH₄ emissions.
- **Components of Carbon Flux Modelling:**
- i. Gas flux measurements: Using floating chambers, eddy covariance systems, or dissolved gas concentration analysis.
 - ii. Biogeochemical process modelling incorporating:
 - Organic matter decomposition
 - Methanogenesis and methane oxidation
 - Photosynthesis and respiration cycles
 - iii. Hydrodynamic models: Simulate water movement and sediment–water interface interactions.
 - iv. Mass balance modelling: Estimates inputs (feed, runoff, fertilizers) vs. outputs (harvest, respiration, emissions).
- **Importance of Carbon Flux Modelling in MRV:**
- i. Provides emission estimates needed to calculate net carbon balance.
 - ii. Helps identify hotspots for mitigation, such as anaerobic sediment zones.
 - iii. Crucial for developing activity-based carbon credit methodologies.

6.2 Remote Sensing and Digital Tools

Remote sensing technologies and digital platforms are transforming MRV in blue carbon aquaculture by enabling high-resolution, continuous monitoring.

- a) **Drones (Unmanned Aerial Vehicles - UAVs):** Drones provide low-altitude, high-resolution imagery ideal for smaller aquaculture systems. It uses include:
- Mapping seaweed farm extents
 - Assessing pond surface area and canopy cover (silvofisheries)
 - Monitoring algal bloom dynamics
 - Sediment resuspension detection (turbidity mapping)
- b) **Satellite Monitoring:** Satellite data supports large-scale and long-term monitoring. Capabilities are:
- Optical data: Biomass estimation for seaweed using reflectance signatures
 - Thermal data: Surface water temperature monitoring
 - SAR (Synthetic Aperture Radar): Year-round monitoring under cloud cover; useful for pond mapping and flooding detection.
- Common Platforms include:
- Sentinel-1 & Sentinel-2

- Landsat 8/9
- MODIS (for large-scale seaweed biomass estimation)
- c) **AI and Machine Learning Applications:** AI enhances the accuracy and automation of MRV systems. Applications in Aquaculture MRV include:
 - Biomass prediction: Neural networks trained on spectral signatures or growth datasets.
 - Automated pond mapping: AI-driven classification of pond boundaries using satellite imagery.
 - Flux prediction models: Machine learning tools predict CH₄ and CO₂ emissions based on environmental variables (e.g., DO, temperature, feed rate).
 - Digital MRV platforms: Integrate IoT sensors (DO, pH, CO₂, turbidity) with cloud databases for real-time carbon accounting.
- d) **Internet of Things (IoT) and Sensor Networks:** Sensors provide continuous in situ monitoring. Measured parameters include:
 - Dissolved oxygen
 - pH
 - Temperature
 - Turbidity
 - Chlorophyll-a
 - CO₂ concentration in water

These data streams improve accuracy and reduce MRV costs.

6.3 Data Gaps and Research Limitations

Despite advancements, major limitations hinder the establishment of robust MRV frameworks for blue carbon aquaculture.

a) Need for Tropical Region Studies

- Most carbon sequestration research has focused on temperate systems.
- Tropical ponds and seaweed farms common in Africa, Southeast Asia, and South America are underrepresented.
- High temperatures and year-round productivity patterns may significantly alter carbon fluxes.
- Localized MRV protocols must be developed for tropical climatic and socio-ecological contexts.

b) Lack of Long-Term Carbon Burial Datasets

- Few studies track sediment carbon accumulation beyond 10 years.
- Long-term datasets are essential for verifying permanence, a key criterion for carbon credits.
- Pond management practices (e.g., dredging, harvesting, drying) disrupt sediment layers, complicating long-term measurements.

c) Limited CH₄ Emission Data

- Methane emissions from aquaculture are highly variable.
- Seasonal and diurnal patterns are poorly documented, particularly in low-income regions.
- Very few studies exist for African and South Asian aquaculture systems.

d) Absence of Standardized Methodologies

- No globally accepted MRV standards for aquaculture blue carbon.
- Carbon credit issuers (e.g., Verra, Gold Standard) lack methodologies for ponds and seaweed farms.
- This limits the ability of farmers to access carbon markets.

e) Technological Barriers

- Remote sensing tools and IoT sensors are expensive for smallholder farmers.
- Data processing requires technical expertise often lacking in developing regions.

MRV in blue carbon aquaculture is essential for validating the carbon benefits of inland ponds, seaweed cultivation, silvofisheries, and shellfish farming. Effective MRV combines field measurements, sediment analysis, carbon flux modelling, and digital technologies such as drones, satellites, AI, and IoT systems. However, significant data gaps particularly in tropical regions and long-term carbon burial studies must be addressed before aquaculture can be fully integrated into global carbon markets.

7.0 Environmental and Socio - economic Co-Benefits of Blue Carbon Aquaculture

Blue carbon aquaculture including seaweed farming, shellfish culture, silvofisheries, and inland/coastal pond systems provides substantial environmental and socioeconomic co-benefits beyond carbon sequestration (Figure 3). These co-benefits enhance ecosystem resilience, improve water quality, support biodiversity, and strengthen community livelihoods.

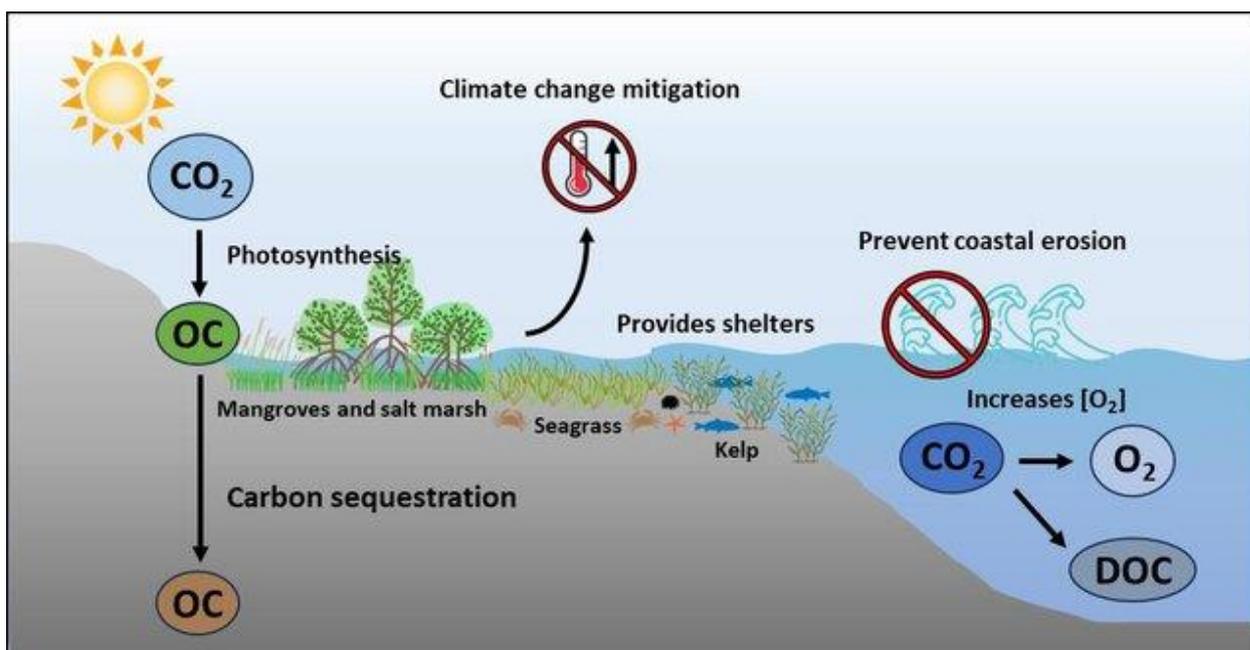


Figure 3: Schematic diagram of the beneficial effects of blue carbon ecosystems

Source: Lee & Lee, 2025

Recognizing these multi-dimensional advantages is essential for integrating aquaculture into climate adaptation and sustainable development strategies. Blue carbon aquaculture systems offer far-reaching environmental and socioeconomic co-benefits (Table 9). They contribute to coastal protection, improve water quality, enhance biodiversity, and support livelihoods and food security. These co-benefits make blue carbon aquaculture not only a climate mitigation tool but also a cornerstone of climate adaptation and sustainable coastal development

Table 9: Environmental and Socio-economic Co-Benefits of Blue Carbon Aquaculture

S/N	Co-Benefit	Explanation
Environmental Benefits		
1	Carbon sequestration	Aquaculture systems integrated with mangroves, seagrasses, and seaweeds capture and store atmospheric CO ₂ in biomass and sediments.
2	Climate change mitigation	Long-term carbon storage in coastal sediments helps reduce net greenhouse gas emissions.
3	Coastal protection	Mangrove-based and seagrass systems reduce shoreline erosion, buffer storm surges, and protect coastal infrastructure.
4	Water quality improvement	Seaweeds and filter-feeding organisms (e.g., shellfish) absorb excess nutrients and pollutants, reducing eutrophication and harmful algal blooms.
5	Habitat and biodiversity support	Blue carbon systems provide nursery and breeding grounds for fish, invertebrates, and other marine organisms.
6	Sediment stabilization	Rooted vegetation traps sediments, reduces turbidity, and enhances long-term carbon burial.
Socio-Economic Benefits		
1	Job creation	Generates employment opportunities in farming, processing, marketing, and ecosystem management.
2	Food security	Increases availability of affordable, nutritious seafood for local and regional populations.
3	Income diversification	Provides alternative livelihoods to fishing communities, reducing pressure on wild fish stocks.
4	Poverty reduction	Stable aquaculture incomes improve household livelihoods and reduce vulnerability to economic shocks.
5	Carbon finance opportunities	Participation in carbon credit and payment for ecosystem services schemes generates additional income.
6	Community resilience	Strengthens local capacity to adapt to climate risks through ecosystem-based and sustainable livelihood strategies.

8.0 Case Studies of Successful Application of Blue Carbon aquaculture Practices

Blue carbon aquaculture practices are increasingly being demonstrated across Africa and Asia, showing measurable ecological, climate, and livelihood benefits (Feng *et al.*, 2023). The following case studies highlight real-world applications of mangrove – aquaculture systems, seaweed farming and shellfish - based carbon solutions.

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Table 10: Case Studies of Successful Applications of Blue Carbon Aquaculture Practices

Country/Region	Blue Carbon Practice	Project / System Description	Outcomes	Success Factors
Vietnam (Mekong Delta)	Mangrove – shrimp integrated farming (Silvofisheries)	Shrimp ponds combined with restored mangrove forests to allow tidal water exchange and natural productivity.	Increased carbon storage in mangrove biomass and sediments; improved shrimp yield; reduced farm disease outbreaks.	Strong community participation, traditional knowledge integration, and government support.
Indonesia	Mangrove restoration with aquaculture	Degraded shrimp ponds were rehabilitated and replanted with mangroves while maintaining low-intensity aquaculture.	Enhanced shoreline protection, carbon sequestration, and sustainable shrimp production.	Large-scale restoration programs and NGO –government collaboration.
China	Seaweed – shellfish integrated multi-trophic aquaculture (IMTA)	Farming of kelp and oysters/mussels in the same coastal systems to recycle nutrients and capture carbon.	High carbon uptake by seaweeds; improved water quality; increased farmer income.	Advanced farming technology and strong market demand for seaweed products.
Bangladesh (Sundarbans region)	Mangrove – fish and crab polyculture	Integration of mangroves with finfish and mud crab culture in brackish ponds.	Greater carbon burial in soils; diversified farm income; improved food security.	Community-based management and climate adaptation incentives.
Philippines	Community-based mangrove–aquaculture systems	Local cooperatives combined mangrove rehabilitation with milkfish and shellfish farming.	Improved coastal resilience; increased fish production; strengthened local livelihoods.	Strong local governance and participatory management.
Australia	Seagrass-friendly aquaculture practices	Low-impact shellfish farming designed to protect and enhance seagrass meadows in coastal bays.	Improved sediment carbon stocks; enhanced biodiversity; sustainable aquaculture growth.	Strict environmental regulations and scientific monitoring.
Mexico	Seaweed farming for carbon capture	Large-scale cultivation of native seaweeds for food, biofuels, and carbon capture.	Significant blue carbon uptake; new green jobs; reduced coastal eutrophication.	Public–private partnerships and innovation funding.

Kenya	Mangrove restoration with crab and fish culture	Community groups replanted mangroves and practiced small-scale cage aquaculture.	Increased forest carbon stocks; enhanced fish nursery habitats; improved household incomes.	Community ownership and NGO technical support.
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Makoko (Lagos, Nigeria) is not usually listed as a “successful blue carbon aquaculture case study” because:

- i. It is informal and unplanned, not designed specifically for carbon sequestration.
- ii. There is limited scientific documentation on its carbon storage capacity.
- iii. There are no clear blue carbon certification or carbon credit frameworks applied there.

This is shown in

Table 11: Lagos Lagoon (Makoko) as potential Urban Blue Carbon Aquaculture

Location	Status as Blue Carbon Aquaculture Case Study	What Happens There	Blue Carbon Relevance	Why It’s Rarely Listed as a “Successful” Case Study
Makoko, Lagos, Nigeria	<i>Emerging / Informal example</i>	Floating fishing settlements, small-scale fish cages, mangrove fuelwood use, and lagoon-based livelihoods within the Lagos Lagoon system.	Mangrove patches and lagoon sediments store carbon; aquatic vegetation contributes to carbon sequestration.	Lacks formal monitoring of carbon stocks, designed conservation – aquaculture integration, and documented climate finance frameworks.

9.0 Future Directions and Research Priorities (Bullet–Narrative Hybrid)

As blue carbon aquaculture continues to gain recognition, several future pathways and research gaps remain critical for advancing its global relevance, scientific credibility, and climate-mitigation potential. Strengthening data, technology, governance, and circular bio-economy linkages will be essential for scaling these systems sustainably.

9.1 Global Scaling Potential

There is increasing interest in expanding blue carbon aquaculture across regions, yet its scalability requires coordinated technical, ecological, and socio-economic frameworks.

- i. Identification of global hotspots where seaweed, mangrove–aquaculture, and low-emission fish farming can maximize climate benefits.
- ii. Cross-country demonstration projects to generate comparative datasets from Africa, Asia, Latin America, and small island states.
- iii. South–South collaboration to share technology, seed stocks, monitoring tools, and best practices.
- iv. Capacity building and farmer training, especially for smallholders in tropical coastal regions.
- v. Integration into national climate strategies, enabling blue carbon aquaculture to contribute to NDCs (Nationally Determined Contributions).

9.2 Innovations in Carbon Capture Technologies

Technological advancement will play a key role in enhancing carbon uptake, monitoring, and overall system efficiency.

- i. Selective breeding and biotechnology to develop high-carbon-sequestering seaweed strains.
- ii. Microbial and enzymatic approaches for accelerating sediment carbon stabilization and reducing methane emissions.
- iii. AI-enabled carbon estimation models that process pond sensor data, satellite images, and flux measurements.
- iv. Advanced aeration systems and precision feeding to reduce GHG emissions from fish ponds.
- v. Nature-based engineering (e.g., floating mangrove modules, integrated seaweed reefs) to widen carbon capture pathways.

9.3 Integration with Circular Economy Models

Circular economy principles offer new opportunities to transform aquaculture biomass and waste into high-value, low-carbon products.

- i. Seaweed-based biochar for soil enhancement and long-term carbon storage.
- ii. Bioplastics and biodegradable packaging derived from algal biomass to replace fossil-based plastics.
- iii. Nutrient recycling loops, where seaweed farms absorb nutrient-rich effluents from fish ponds.
- iv. Bioenergy and anaerobic digestion, converting sludge and discarded biomass into renewable energy.
- v. Eco-friendly fertilizers and feed additives produced from aquaculture by-products, closing resource loops.

9.4 Need for Harmonized International Blue Carbon Protocols

Standardization is essential if blue carbon aquaculture is to be recognized within global carbon markets and climate accounting systems.

- i. Development of unified MRV methods for ponds, seaweed farms, silvofisheries, and integrated systems.
- ii. Creation of internationally accepted baselines for carbon sequestration and GHG emissions.
- iii. Clear rules on carbon ownership and benefit-sharing, especially for community-managed ecosystems.
- iv. Coordination between UNFCCC, IPCC, and regional bodies to include aquaculture in blue carbon definitions.
- v. Stakeholder-driven frameworks ensuring equity, transparency, and scientific rigor in carbon credit generation.

10.0 Conclusion

Aquaculture presents a transformative opportunity for climate mitigation through blue carbon pathways, complementing traditional natural carbon sinks. Both coastal and inland culture systems, including mangroves, silvofisheries, seaweed farms, shellfish aquaculture and freshwater pond sediments demonstrate substantial carbon sequestration potential while delivering co-benefits such as biodiversity enhancement, coastal protection, water quality improvement, and sustainable livelihoods.

Blue carbon aquaculture provides a unique opportunity to address multiple challenges simultaneously: mitigating climate change, restoring degraded ecosystems, improving water quality, supporting biodiversity, and enhancing livelihoods. Integrated, science-based, and socially inclusive approaches are essential to realize these benefits at scale. By bridging food security, ecosystem restoration, and climate action, blue carbon aquaculture can serve as a cornerstone of sustainable coastal and inland resource management, contributing to resilient and low-carbon development pathways worldwide.

Blue carbon aquaculture is affiliated to SDG 1 by alleviating poverty through the support of coastal livelihoods; SDG 2 by instilling food security through protein production thereby achieving SDG 3 - good health and wellbeing, through feeding on nutritious food; SDG 8 through the availability of decent work and economic growth by providing jobs in the blue sector of the economy; SDG 13 - Climate Action, as a result of reduction of adverse environmental impacts due to carbon sequestration and SDG 14, sustaining life below water through the sustenance and protection of marine habitat.

Ultimately, positioning aquaculture as a nature-based climate solution offers a pathway toward low-carbon, resilient and productive food systems, aligning food security with global climate mitigation goals.

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