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Assessing the Potential of Mangrove Restoration as a Nature-Based Solution for Carbon Sequestration in the Niger Delta Region, Nigeria

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ABSTRACT
Africa's largest mangrove ecosystem is found in Nigeria's Niger Delta, which is key to the continent's carbon sequestration and mitigation of climate change. However, exotic species, deforestation, oil spillage, and uncontrolled development are seriously harming this environment. This research investigates how mangrove restoration may be used in the Niger Delta as a nature-based solution (NbS) for biodiversity preservation, carbon sequestration, and socioeconomic resilience. Based on the PRISMA paradigm, the study assesses the ecological, carbon, and socio-economic effects of current restoration initiatives via a systematic review methodology. Results show that regenerated mangroves may support fisheries, increase coastal resilience, and trap carbon at rates higher than terrestrial forests. However, persistent pollution, inadequate administrative frameworks, and a lack of funding make rehabilitation difficult. Community-driven initiatives and collaborations, such as the Delta Azure Program and UN-REDD projects, show inclusive, scalable approaches that improve both human and environmental well-being. An important chance to address climate change is provided by the inclusion of mangrove habitats in Nigeria's Nationally Determined Contributions (NDCs) under the Paris Agreement. To use mangrove restoration as a weapon for climate mitigation and sustainable development, the research ends by suggesting multi-sectoral cooperation, more funding, and stricter regulations. This will establish the Niger Delta as a global leader in blue carbon solutions.
Keywords: Mangrove restoration, carbon sequestration, Niger Delta, nature-based solutions, climate change mitigation

1. INTRODUCTION

Coastal blue carbon (CBC) ecosystems, usually tidal marshes, seagrasses, and mangroves are found in all the continent except Antarctica and are good sink for carbon sequestrations, ocean health, and even human wellbeing. CBC covers 3.8 to 15.2 million hectares (Mha) in which about 20 % to 50 % have been converted or destroyed [1], [2]. Zooming on the mangroves as the most effective CBC ecosystem for sequestering carbon [3], they consist of typical shrubs and tree species that exhibit adaptations to unstable, low-oxygen soil, and regular submersion, as well as Fauna are considered part of the ecosystem . They are recognized for their significant ecological, economic, social, and cultural value due to the diverse products and services they offer. Therefore, its restoration will be of great value in addition to enhancing the livelihood of the host communities or nations as well as a panacea to tackling climate change. Mangrove restoration, as a nature-based solution (NbS) for climate mitigation, creates an environment for carbon capture and sequestration (CCS), while preserving the biodiversity and coastal resilience [4]. Recognized under the Paris Agreement (PA) of 2015, mangroves with the current global average carbon stock of 2790 tCO_2eq/ha can sink 3-5 times more carbon than terrestrial forests, contributing to almost 10 % (37 $GtCO_2eq$) of global terrestrial carbon pool, supporting Nationally Determined Contributions (NDCs) to reduce emissions [5], [6], [7]. The two key conventions, the Convention on Biological Diversity (CBD), and the United Nations Framework Convention on Climate Change (UNFCCC) and highlights mangrove conservation will help to achieve global climate targets of net zero by 2050, given their dual role in ecosystem protection and carbon sequestration [8], [9]. By including mangrove restoration within NDCs, climate action and biodiversity protection may work together in accordance with the Kunming-Montreal Global Biodiversity Framework, aimed at tackling the current loss of biodiversity and securing the health of the global ecosystems [10]. Therefore, addressing mangrove ecosystems can protect vulnerable coastal communities and provide the needed scalable climate solutions. Programs like the United Nations Decade on Ecosystem Restoration, aimed to "prevent, halt and reverse the degradation of ecosystems on every continent and in every ocean" [11] can encourage the restoration of mangroves in tropical coastal regions such as Niger Delta region of Nigeria and other coastal areas of Africa, where deforestation has resulted in considerable emissions. However, achieving the needed conservation requires mangrove restoration integrating ecological studies with socioeconomic tactics, which has demonstrated a cost-effective and scalable approach to achieving biodiversity, coastal resilience and net zero goals. As a scientifically validated nature-based carbon sequestration, mangrove restoration leverages ecological principles to tackle climate change [12]. One of such principles is the biogeochemical cycle. It theoretically explains the interactions and processes on how elements and compounds such as Nitrogen, phosphorus, carbon, etc. are cycled and recycled between the living organisms and the environment (atmosphere, hydrosphere, geosphere, and other Earth reservoirs). It also describes how carbon is retained in peat layers. To understand the movement and changes of elements and compounds within ecosystems and the Earth in total, it involves integrating biological, geological, and chemical principles [13], [14].

The Niger Delta region of Nigeria, stretched across nine (9) states, covering ~ 800,000ha and estimated with a carbon stock of 2.2 $GtCO_2eq$ is the Africa's largest mangrove ecosystem, third largest in the world, and a good natural asset for global carbon sequestration and climate regulation [5], [15], [16]. These ecosystems not only help in mitigating climate change but also provide solutions such as coastal protection, biodiversity conservation, and enhance the local livelihood. However, the mangroves of Niger Delta are undergoing gradual but steady loss and severe degradation over the past few decades, with an estimated 12 % decrease in mangrove coverage between 2007 and 2017 in what was described as "grave danger" due to oil spills, deforestation, and invasive species [17]. According to a recent study [18], Bayelsa state, Delta state, and Rivers state lost 8274 ha, 4824 ha, and 2281 ha respectively of their mangrove forests coverage between 1996 and 2016, at corresponding rates of 413.7, 241.2, and 114.1 ha per year. These declines threaten both ecological stability and the livelihoods of the local communities and the affected states, hence the need for restoration efforts. The restoration initiatives are strained by pollution and lack of financing. Local communities and non-governmental organizations (NGOs) are advocating

environmentally sustainable extraction practices and replanting initiatives [19]. The motivation for this research stems from the growing interest in NbS as one of the sustainable approaches to tackling climate change while delivering co-benefits for biodiversity and human well-being. No doubt that mangrove restoration has gained traction as a cost-effective strategy for carbon sequestration, with the potential to contribute significantly to Nigeria's Nationally Determined Contributions (NDCs) under the Paris Agreement (PA), but large-scale restoration efforts in the Niger Delta region face enormous barriers, such as oil pollution, limited financing, and weak legal, policy, regulatory frameworks and enforcement. Understanding these issues and identifying scalable and sustainable solutions is critical to unlocking the full potential of mangrove restoration in the region as a climate mitigation tool.

This review aims to evaluate the viability of mangrove restoration as a NbS for carbon sequestration in the Niger Delta, emphasizing existing initiatives, carbon offset potential, and socio-economic effects, while providing practical recommendations for policymakers, conservationists, and local host communities. The findings will contribute to the wider conversations on integrating mangrove ecosystems into global climate plans while tackling the environmental and socio-economic concerns of the Niger Delta.

2. METHODOLOGY

This review adopts the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to evaluate mangrove restoration strategies in the Niger Delta, focusing on ecological, socio-economic, and carbon sequestration outcomes. The PRISMA flow diagram (**Fig. 1**) shows the systematic review process, in which 284 records were initially identified, however 261 from databases and 23 manually. After removing 21 duplicates, 168 titles were screened, leading to 120 abstracts being reviewed. Following exclusions for scope, accessibility, and language, 97 full-text articles were assessed. Finally, 71 studies from databases and 13 from manual searches met eligibility criteria, resulting in a total of 84 studies included in the study. The methodology comprises four phases: (1) identification of peer-reviewed studies from Google Scholar and google search using keywords like "mangrove restoration," "Niger Delta," "blue carbon," and "community engagement"; (2) screening based on inclusion criteria (field-based studies, quantified restoration outcomes, and clear methodologies) and exclusion of non-empirical or non-regional research; (3) eligibility assessment through full-text review to extract data on success metrics (survival rates, carbon stocks, livelihood impacts); and (4) synthesis using qualitative and quantitative analysis.

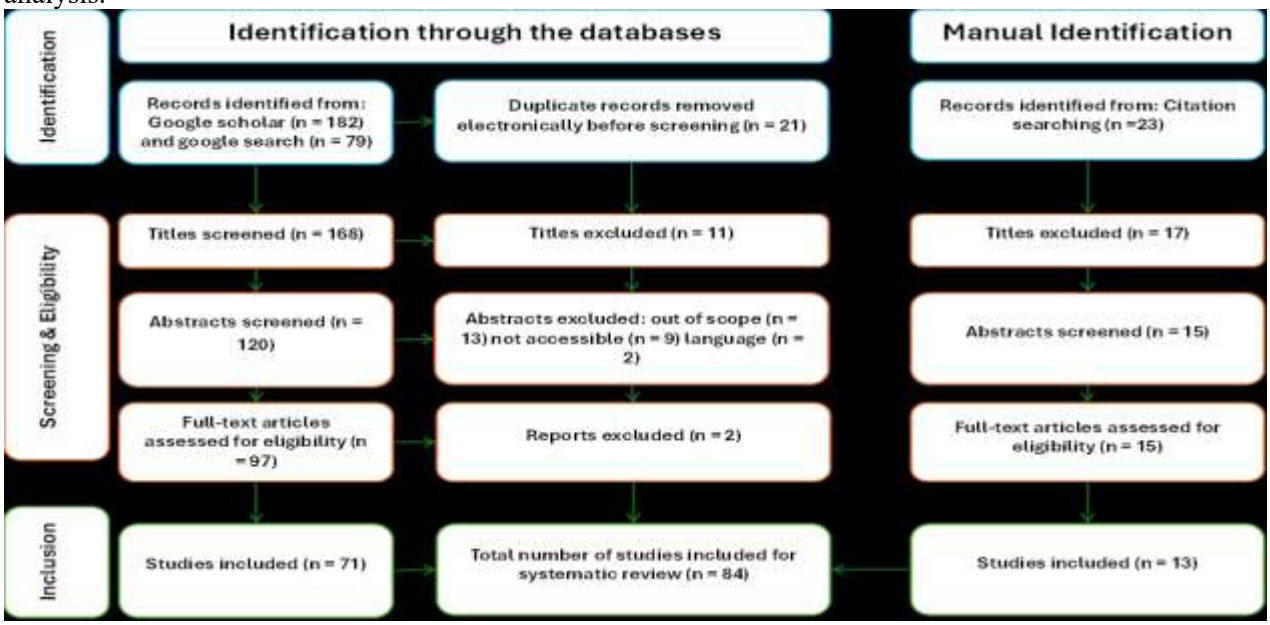

Fig. 1: Research Methodology - PRISMA Framework

3. DISCUSSIONS

3.1. Extent, Biodiversity and Degradation Factors of Mangrove Ecosystems in the Niger Delta

The Niger Delta's mangrove forests represent one of the most ecologically significant wetland ecosystems in the world, covering ~ 4,054 square miles [18], [20]. The extent of mangroves in Nigeria has decreased by 62.5 square miles between 1996 and 2020 [21]. **Fig. 2** shows mangrove dynamics in the region as of June 2025, presenting the extensive coastline mangrove coverage, significant deforestation alerts, and key restoration zones. It includes maps of protected areas, carbon stock (blue carbon), and mangrove-dependent fisheries. Regions such as the Niger Delta show high deforestation and restoration potential, reinforcing the urgency for conservation efforts targeting biodiversity, climate resilience, and livelihoods [22]. These biodiverse ecosystems are dominated by mangrove species such as Avicennia germinans, Rhizophora racemosa, and Laguncularia racemosa, which have adapted to the region's brackish water conditions and tidal fluctuations [23], [24]. The forests are indispensable for maintaining ecological balance and supporting local fisheries because they provide necessary habitat for a wide variety of aquatic and terrestrial species, such as fish, crustaceans, and migratory birds that are valuable to the economy [15]. The Niger Delta states, particularly Bayelsa, Rivers, and Akwa Ibom, host Nigeria's largest mangrove forests, with high carbon stock (500 - 1200 Mg C/ha) and sequestration potential (10 - 18 t CO_2e/ha/yr), but face severe declines due to oil spills, invasive species such as the Nypa palm, and urbanization. Restoration efforts, such as UNDP-funded projects, Nypa eradication, and community replanting, are active in these states, while Cross River benefits from the "Reducing emissions from deforestation and forest degradation (REDD+)" programs. Smaller mangrove areas in Edo, Ondo, Imo, and Abia suffer from logging and pollution, with minimal restoration. Lagos, though limited in coverage (~70 km^2), has emerging initiatives like the Lagos State Mangrove Park and NGO-led projects to counter reclamation and urban pressures. According to study [25], The invasive Nypa palm is rapidly clearing and encroaching on the Niger Delta mangroves, thereby endangering over a million hectares of mangroves in the region. From **Fig. 3** [21], the extent of mangrove in the Niger Delta and world as a whole have decreased by 62.5 and 2025.2 square miles respectively between 1996 and 2020. Bayelsa has the highest coverage (~3,165 km^2) and carbon sequestration capacity (600-1,200 Mg C/ha), while Abia has the least (50 km^2). Major threats include oil spills, deforestation, and urbanization. Restoration efforts vary, with Rivers State and Delta State benefiting from IUCN and UNDP projects, while Edo and Abia States lack large-scale initiatives [18]. The biodiversity status and extent in Niger Delta Mangroves are summarized in **Table 1**.

Table 1: Summary of the Biodiversity Status and Threats in Niger Delta Mangroves

Metric	Findings	Implications	[Ref.]
Mangrove Coverage Loss	62.5 square miles lost (1996–2020); Bayelsa lost 8,274 ha (1996–2016).	Highlights urgent need for restoration to prevent ecosystem collapse.	[18], [21]
Key Species	Dominant: *Avicennia germinans*, *Rhizophora racemosa*, *Laguncularia racemosa*.	Native species are critical for carbon sequestration and habitat stability.	[24]
Invasive Nypa Palm	28,000 ha converted to Nypa by 2020; projected full invasion by 2028.	Nypa reduces biodiversity by outcompeting native mangroves and altering hydrology.	[26]
Oil Spill Impact	14,053 spills (2006–2022); 754,196 barrels spilled, contaminating roots/sediments.	Hydrocarbons suppress propagules and disrupt soil microbiomes, reducing species diversity.	[24], [27]
Fisheries Decline	Fish populations drop by 40–60% in oil-impacted zones (Osuagwu & Olaifa 2018).	Loss of nursery habitats threatens food security and livelihoods.	[28]

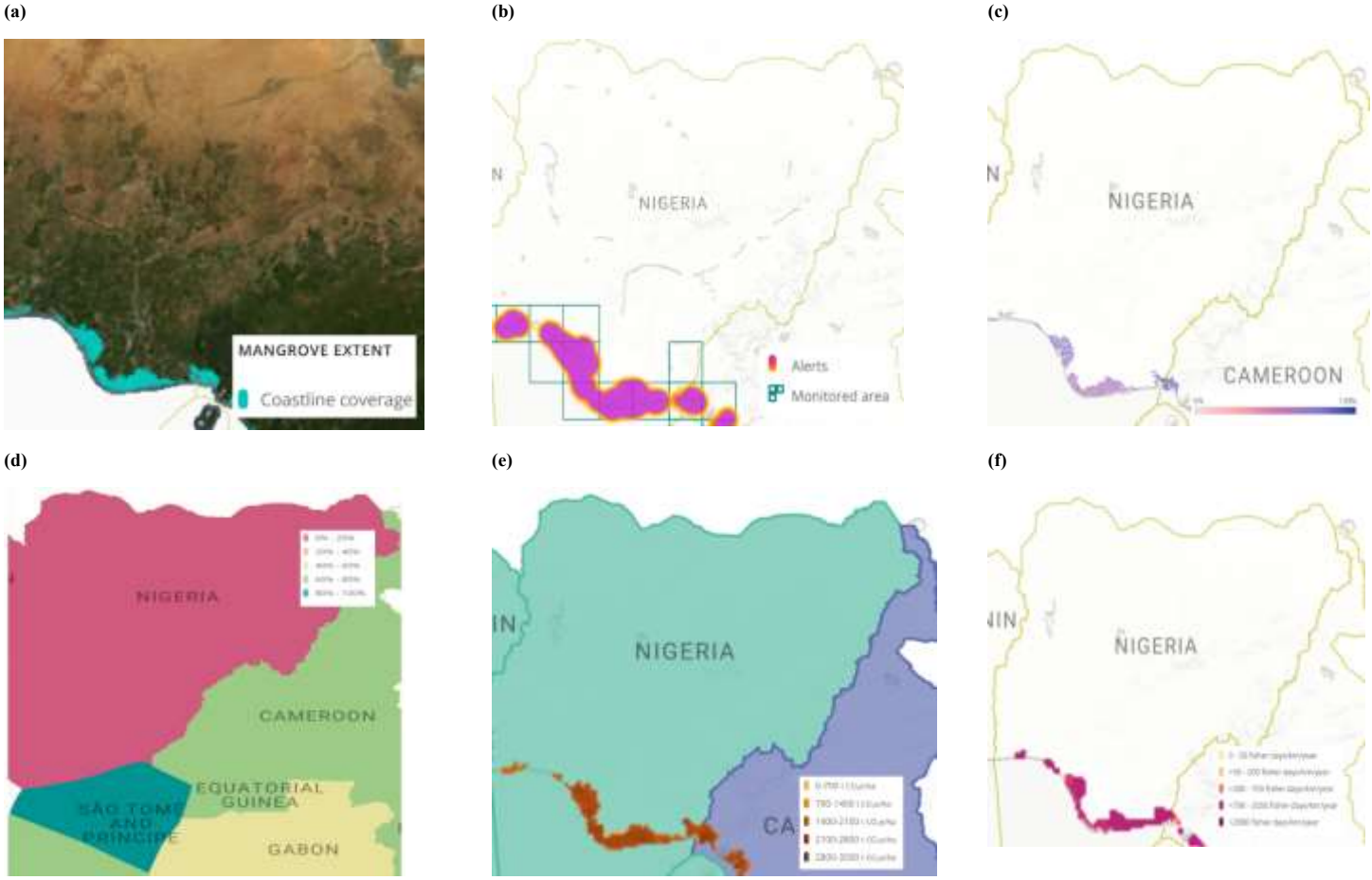

Fig. 2: Niger Delta Mangrove as of May 2025 (a) Satellite Imagery of the Niger Delta Mangrove coverage, (b) Mangrove Deforestation Alerts, (c) Mangrove Restoration Potential, (d) Mangrove Protected Area, (e) Mangrove Blue Carbon, and (f) Mangrove Fisheries (**Source**: generated from the Global Mangrove Watch Map Box [21], and Bunting P. *et al*. (2018) [22].

(a) (b)

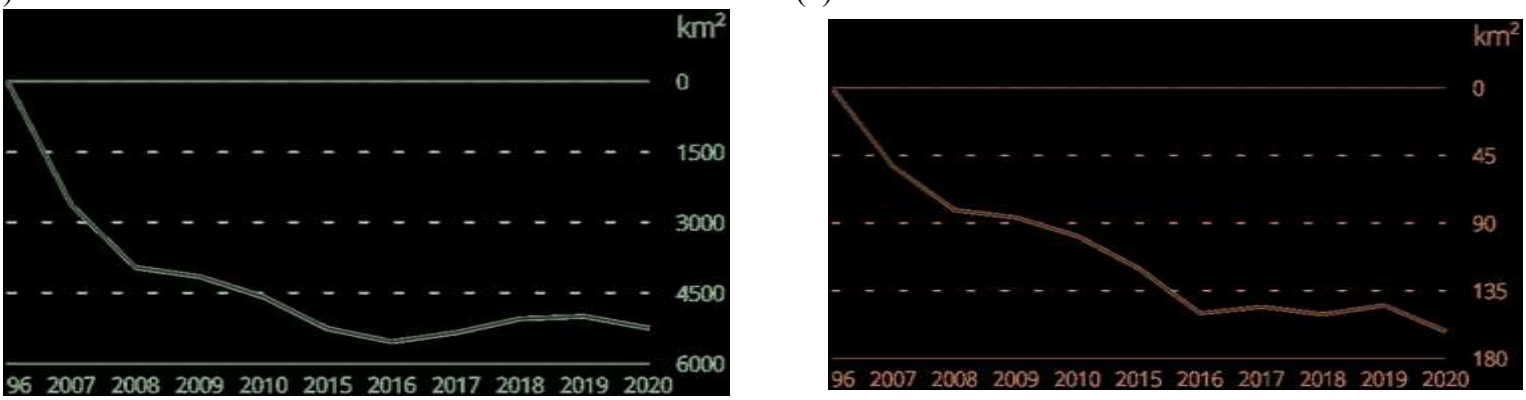

Fig. 3: The extent of decreased mangroves in (a) Niger Delta region and (b) the world (**Source**: generated from the Global Mangrove Watch Map Box)

Also, oil spills are another major degradation factor in the region's mangrove, a continuous result from crude oil production has been damaging, covering roots and sediments with toxic hydrocarbons that suppresses mangrove propagules and disrupt soil microbiomes [24], [29]. The region accumulates around 240,000 barrels of oil spills per year, with ongoing pollution making many areas unfit for natural regeneration [30]. Another study (**Table 2**) [27] recorded number of spills and barrels spilled at 14,053 and 754,196.44 bbls respectively, that have ravaged the mangrove ecosusytem. Urbanization and agricultural expansion further exacerbate mangrove loss, as forests are cleared for real estate developments, settlements, industrialization and farmland [24], [31]. These cumulative pressures have not only diminished carbon sequestration capacity but also eroded the coastal resilience of the communities to climate impacts. At this point, successful restoration and addressing of the degradation drivers will inevitably require a multi-faceted strategy, combining environmental regulations, pollution and invasion control measures, funding, community and stakeholders' engagements to sustain and ensure the survival of these critical ecosystems. In Delta state, Serendib Capital, Eight Versa and Foundation for Partnership Initiatives in the Niger Delta (PIND) in a partnership with the Delta State government are conceptualizing a large-scale mangrove restoration and conservation project in Nigeria's Niger Delta region, expected to be second to the largest in the world, sequestering ~ 5.3 million tCO_2e/yr, and consequently preventing logging and removal of 250,000 ha of the forest [32]. In Rivers State, a proposed 240,000-hectare mangrove restoration project partnership between Serendib Capital, Eight Versa, PIND and the state government has been initiated, with the integration of mangrove restoration, seagrass conservation next to 170,000 ha of mangrove, sustainable agriculture, tree planting, biochar production, and other activities. It is expected to become the biggest blue carbon project in the world, and a component of Delta AZURE, a wider initiative to restore mangrove maritime ecosystems [17], [33].

Table 2: Oil Spill Incidents in the Niger Delta (2006–2022)

Year	Number of Spills	Barrels Spilled	Litres Spilled	Equivalent Oil Tanker Trucks
2006	378	24,723.00	3,906,378.39	124
2007	1,012	70,795.77	11,185,731.63	354
2008	997	96,847.35	15,301,880.77	484
2009	857	36,988.09	5,844,118.74	184
2010	889	47,261.02	7,467,240.61	236
2011	1,058	73,131.01	11,554,669.71	366
2012	1,135	41,802.00	6,604,716.42	209
2013	1,167	32,295.16	5,102,634.84	161
2014	1,521	78,890.46	12,464,692.78	394
2015	920	47,701.63	7,536,857.28	239
2016	684	42,734.53	6,752,055.53	214
2017	600	35,041.18	5,536,505.72	175
2018	692	25,079.68	3,962,589.82	125
2019	710	38,212.32	6,037,546.68	191
2020	433	21,049.58	3,325,833.19	105
2021	404	22,788.38	3,600,563.77	114
2022	596	18,855.19	2,979,120.27	94
Total	**14,053**	**754,196.44**	**119,163,166.14**	**3,769**

From 2006 to 2022, the Niger Delta saw 14,053 oil leaks, resulting in the loss of 754,196 barrels (119 million liters), sufficient to fill 3,769 tanker trucks. The most catastrophic year was 2014, recording 1,521 leaks and a loss of 78,890 barrels, succeeded by 2008 with 96,847 barrels lost. Spills have decreased in previous years, with 2022 recording the lowest volume at 18,855 barrels. Primary factors encompass sabotage, vandalism, and aging pipelines, with several instances reaching 40 years significantly beyond their 15–20-year expected lifespan. Severe economic and environmental harm requires immediate legislative changes and more stringent enforcement to stop more destruction.

3.2. Key Mangrove Ecosystem Restoration Initiatives in Nigeria

Niger Delta Mangrove Restoration Project (NDMRP): This was launched in 2018 by the Niger Delta Development Commission (NDDC) targeting emission reduction of 30.000 tCO_2e per annum [34]. It (**Fig. 4**) represents one of Nigeria's most ambitious efforts to rehabilitate degraded mangrove ecosystems across Nger Delta region. This initiative aims to restore and sustainably manage the Niger Delta mangroves, a biodiversity hotspot of great interest on Nigeria's Atlantic coast that provides food and livelihoods for millions. These mangroves provide critical ecosystem services by controlling climate, preventing floods, supplying resources like timber and medicine, and acting as nurseries for marine life. Despite their importance in carbon sequestration and pollution filtering, these mangroves are being severely degraded due to deforestation, gas flaring, and land conversion, leaving coastal people exposed to flooding, heatwaves, and lost livelihoods. This project seeks to plant 100,000 mangroves over three (3) years in four Akwa Ibom communities (Eket, Esit Eket, Ibeno, and Mbo), with the goal of eventually reaching 1 million trees. It involves ~ 100 local young volunteers and offers advantages such as improved ecosystems, greater fish populations, less erosion, and work opportunities for 5000 fishermen and 3000 women. In line with global conventions such as CBD and RAMSAR, the initiative wants $36,000 to reach its $50,000 budget, which implies $0.50 per tree. Contributions ranging from $20 to $500 can plant 40 to 1000 trees, directly benefiting climate resilience and poverty reduction [35], [36], [37].

Fig. 4: NDMRP - Project Image [38]

***Agba-Okwan Asarama Mangrove Restoration Project (Rivers State)*:** This (**Fig. 5**) was created in April 2024, and it represents an integrated approach to ecosystem restoration in Rivers State. This project is led by Envy Nature, aims to rehabilitate degraded mangrove ecosystems in Asarama, Niger Delta, to combat biodiversity loss and climate change while supporting local livelihoods. Mangroves in this region are important for carbon sequestration, coastal protection, and providing habitat for fish and other marine species, but they face severe threats from deforestation, pollution, and unsustainable exploitation. This initiative plans to restore 50 ha of mangroves by planting 100,000 seedlings, engaging local communities in conservation efforts, and promoting sustainable resource management. Key objectives include improving the ecosystem resilience, reducing coastal erosion, and improving food security by reviving fisheries. The project also empowers women and youth through training in mangrove restoration and eco-friendly livelihoods, fostering long-term environmental stewardship. There is need to strengthen climate adaptation and community resilience by integrating with global frameworks such as the Paris Agreement and the United Nations Sustainable Development Goals (SDGs), for instance SDGs 13 (Climate Action), 14 (Life Below Water), and 15 (Life on Land). Performance will be assessed by mangrove survival rates, biodiversity regeneration, and socioeconomic benefits to coastal communities. Strategic partnerships and funding to scale its impact are critical to ensure a sustainable future for Niger Delta's mangroves and the communities that depend on them [39], [40], [41], [41], [42].

Fig. 5: Agba-Okwan Asarama Mangrove Restoration Project [39]

DeltaAzure Blue Carbon Program: This landmark initiative intends to strengthen local communities via sustainable practices while restoring Nigeria's mangrove ecosystems. The project, which spans over 520,000 ha of mangroves, intends to improve biodiversity, increase carbon sequestration, and support local economies by restoring 375,000 - 470,000 ha of seagrass, with additional ~35,000 ha identified for afforestation. Using its creative Carbon Mosaic approach, Delta Azure program balances ecological and community advantages by combining mangrove preservation, sustainable agriculture (82,000 ha), and biochar production (610,000 tons/yr). The initiative, which mostly operates in Delta and Rivers States, enhances livelihoods and builds resilience against climate change by involving 135 communities in citizen science, beekeeping, and oyster farming. Restoration is imperative as mangroves, which are carbon sinks and coastal defenders, are threatened by pollution and deforestation. Through the integration of economic opportunity and environmental preservation, Delta Azure's community-centered strategy assures long-term sustainability. The program aims at setting a global benchmark for blue carbon projects that create a balance between ecological health and human prosperity by expanding to Lagos and Bayelsa, where Delta and Rivers States have already committed [33], [43], [44], [45].

Lokiaka Community-Led Restoration Efforts (Ogoni Land): Grassroots mangrove restoration efforts (**Fig. 6)** led by organizations like the Lokiaka Community Development Centre (~40 square km of mangroves) which has been destroyed because of oil spillage in the Ogoni region, demonstrate the power of local knowledge in ecosystem rehabilitation. These initiatives have pioneered gender-inclusive conservation models, with women at the forefront of reforestation efforts, and have grown millions of mangrove trees in the region, transforming the lives of the Ogoni people who have been suffering from oil spills, deforestation, and invasive Nypa palms for decades.

Fig. 6: Community-Led Restoration Efforts in Lokiaka (Image courtesy of Lokiaka Community Development Centre [46])

These initiatives' inclusive approach, which incorporates traditional ecological knowledge into planting techniques and species selection, was key determinant to their success. To increase survival rates in places affected by oil, women's organizations have created innovative approaches such as biodegradable seedling shields built from locally available materials. In addition to their ecological advantages, these initiatives have produced other sources of income through ecotourism and sustainable aquaculture projects connected to mangrove restoration sites. One of such is the Ogoni women's restoration network, which has created community savings initiatives financed by the manufacture of mangrove honey and crafts made from non-timber forest products [46], [47], [48]. The strategy has sparked replication throughout the Gulf of Guinea, showing that, with the right regulatory frameworks and financing mechanisms in place, bottom-up conservation can have a scalable impact. Additionally, these initiatives have improved

social cohesiveness in places that have gone through war, revealing that environmental restoration may serve as a means of promoting peace in the region, and beyond.

UN-REDD Mangrove Restoration Initiative: The UN-REDD Programme in Cross River State tackles significant issues, such as deforestation due to fuelwood extraction, invasive Nypa palm invasion, and poverty-induced forest degradation. More than 50 % of Nigeria's tropical forests are in Cross River; yet, local people depend significantly on mangroves for energy and money, with some selling mangrove wood for as little as $0.75 per 6 kg [49]. The invasive Nypa palm accelerates biodiversity loss and eliminates aquatic life, thereby jeopardizing local livelihoods. Delays in financing and limited resources continue to be key challenges to expanding restoration initiatives. Since 2010, the initiative has involved 540 households (2,000 individuals) in 18 projects, demonstrating quantifiable results. More than 10,000 mangrove seedlings have been planted, resulting in less floods and enhanced fish habitats in restored [49]. Training in nurseries and sustainable agriculture such as cassava, bush mango) has alleviated deforestation pressures. Notably, Nypa palm clearing, driven by women has improved native mangrove regeneration, and community management plans now control mangrove harvesting. Given that mangroves store four times as much carbon as tropical forests, these initiatives demonstrate the connection between mangrove development and climate resilience. Triple breakthroughs have resulted from the initiative: social successes such as female empowerment and poverty alleviation, economic successes such as alternative livelihoods (cassava processing) and ecological successes such as biodiversity recovery and carbon sequestration [50]. Fishermen have reported that fish populations have recovered because of the $800,000 investment from UN-REDD and the Global Environment Fund, which has increased community ownership [51]. To duplicate accomplishments throughout Nigeria's Niger Delta and meet national climate targets, scaling up calls for quicker access to financing and more extensive capacity building [49].

By and large the summary of biodiversity outcomes of restoration initiatives is presented in **Table 3**

Table 3: Summary of Biodiversity Outcomes of Restoration Initiatives

Initiative	Intervention	Biodiversity Outcomes	Lessons Learned
NDMRP (Akwa Ibom)	Planted 100,000 mangroves; targeted 1M trees.	Increased fish populations; reduced erosion.	Community engagement boosts survival rates (~70%).
Agba-Okwan Asarama (Rivers)	50 ha restored; 100,000 seedlings planted.	Revival of crustacean and migratory bird habitats.	Gender-inclusive programs enhance long-term stewardship.
DeltaAzure Program	375,000–470,000 ha seagrass + mangrove restoration.	Carbon stocks increased by 600–1,200 Mg C/ha; native species reintroduced.	Hybrid livelihoods (e.g., oyster farming) reduce pressure on mangroves.
Lokiaka Community Efforts	40 km² restored; women-led nurseries.	80% survival rate for *Rhizophora* spp.; ecotourism developed.	Traditional knowledge improves species selection.
UN-REDD (Cross River)	10,000 seedlings planted; Nypa eradication.	Fish habitats recovered; invasive species reduced by 50%.	Training in sustainable agriculture reduces deforestation.

Nigerian Conservation Foundation (NCF) Coastal Resilience Project: The NCF is carrying out wide range of projects (**Fig. 7**) across Nigeria to tackle environmental issues, improve community livelihoods, and protect biodiversity. Some of these projects include but not limited to following; the Lekki Conservation Centre (LCC) in Lagos State, the Omo-Oluwa-Shasha Conservation Project in Ogun, Ondo, and Osun States, the Nypa Palm Utilization Project in Akwa Ibom State, the Management of Becheve Nature Reserve at Obudu Cattle Ranch in Cross River State, the Biodiversity Action Plan (BAP) Project in Edo State, the Wing Over Wetlands (WOW) initiative in Gombe and Jigawa States, the A.P. Leventis Ornithological Research Institute (APLORI) in Plateau State, the Participatory Forest Management Project at Mambilla and Donga sites in Taraba State, and its Important Bird Area Program, all of which

promote ecological preservation and sustainable development across the country [52]. By planting mangroves such as Rhizophora mangle and Avicennia germinans, beside low-crested breakwaters created from recyclable materials, the NCF's creative hybrid engineering strategy integrates ecological restoration with infrastructure [53], [54]. This strategy has also prevented the erosion of affected coastal communities and reduced wave energy in protected zones. However, when compared to conventional techniques the project's mobile mangrove nurseries, floating barges with solar-powered irrigation, could improve survival rates and allow propagule cultivation in isolated, inaccessible areas. Engagement with the community is key, including capacity building in mangrove-friendly aquaculture such as crab farming to ensure livelihoods correspond with conservation objectives [55]. Progress can be monitored using drones and satellite imaging [56]. A potential drawback is plastic pollution that clogs root systems; this could be handled via waste-recycling partnerships and beach clean-ups. Due to this effectiveness, the initiative is being replicated in three other states, and plans are in place to use blue carbon funding to expand.

Fig. 7: Major Conservation Project Sites in Nigeria

Shell Petroleum's Biodiversity and Ecosystem Program: In an effort mitigate the impact on the environment, Shell engages in biodiversity and ecosystem projects, targeting habitat restoration, sustainable land use, and collaborations with conservation organizations. Among its initiatives are the

restoration of mangroves, the preservation of endangered species, and the mitigation of operational damage to the ecosystem [57]. This functions within the framework of the company's corporate social responsibility (CSR) initiatives [58], focusing on mangrove restoration in environmentally fragile regions such as Ogoniland and Bonny Island. According to UNEP's assessment of Ogoniland [59], there has been significant, decades-long oil pollution from their activities, with 8 cm of oil layers contaminating groundwater and benzene levels in drinking water that are 900 times higher than WHO limits. The study found severe environmental degradation, including bitumen-coated mangrove die-offs and soil hydrocarbons 1,000× over permissible levels, after analyzing more than 4,000 samples from more than 200 locations. 10 high-risk areas require immediate cleanup, and it might take 25 to 30 years for them to completely recover. The well-being of over 1 million citizens is at risk due to systematic inadequacies in artisanal refining and petroleum infrastructure maintenance, as highlighted in the research. In an earlier study [60], the preliminary cost estimate for the mangrove restoration and rehabilitation was US $25.5 million, and for it to restored, local nurseries should be set up to provide healthy, native vegetation. Red mangroves near the coastline and white mangroves inland, which have been most negatively affected, will be the main targets of this rehabilitation. Additionally, invasive species control will be a key component. Also, to address the ecological, health, and economic concerns in the region, a 30-year restoration plan, once the ongoing pollution is stopped, and sustainable actions taken [59]. Furthermore, from assessment by UNEP in Bodo West, on the remote sensing, between 2007 and 2011, it showed artisanal refining increased, resulting in a 10 % loss of healthy mangrove cover in Bodo West, Bonny LGA. The sole remediation solution that UNEP observed in Ogoniland was enhanced natural attenuation (RENA), which increases the ability of microbes to degrade oil. However, in 49 cases, hydrocarbons were discovered in soil at a depth of at least 5 meters, suggesting that this approach has not been effective. Currently, Shell only uses this method on the land surface layer [59]. In recent times, the £55 million settlement between Shell Petroleum Development Company (SPDC) and the Bodo community has gained interest in the petroleum sector, through an environmental philosophy known as the Polluter Pay philosophy (PPP), which guarantee that the ecosystem be restored to its pre-pollution condition, covering liabilities, cleanup expenses, control methods, and prevention [61]. Following this devastating 2008–2014 oil spills that contaminated over 1,000 ha of mangroves and all of the marine life which the locals relied on for livelihood [62], It is hoped that the survival of new mangroves will encourage natural remediation of the land and that Bodo's ecosystem will return to a clean and productive state. Phase 1 of the cleanup, which involved removing surface contamination and preparing for the subsequent phases, is now complete. Phase 2 of the cleanup, which involved removing and flushing oil from the soil, is currently underway. The third and final phase of the cleanup will begin in 2021, concurrently with the completion of the second phase. Development of mangrove seedlings will be monitored until 2028 [63], [64].

Nypa Palm Eradication Program: In the Niger Delta area of Nigeria, the invasive Nypa palm is threatening the mangrove restoration, when compared to its native Southeast Asia, where it has been helpful in carbon sequestration and coastal resilience. This loss is made more devastating by the region's urbanization and petroleum prospecting. According to research [26] that used machine learning and multi-sensor satellite data, by 2020, almost 28,000 hectares of mangroves had been transformed into Nypa, which is more than indigenous mangroves. Additionally, the study discovered that the whole study region may be invaded by 2028 and that Nypa structural variability is smaller than that of mangroves. However, Garba, N. A*., et al*. (2019) [65], investigated the region of Nigeria's Nypa palm sap's capacity to produce bioethanol. It was discovered that 747 million litres of bioethanol could be potentially generated yearly under various sap yield scenarios, meeting 15–36 % of the country's bioethanol need. According to the study, to produce bioethanol from Nypa palm sap, the Nigerian government should create appropriate biofuels legal, policy and regulatory frameworks to drive the initiatives. While this may look like a circular pathway, these claims need to be further investigated for implementation.

In the Bodo cleanup region, Nypa palms are outnumbering mangroves in restoring damaged areas, hence reducing habitat for fishing nurseries and mangrove biota. And to make room for mangrove relocation and future planting, Bodo cleanup efforts include manually removing Nypa seedlings and trimming bigger

plants. The Nypa palm may spread quickly across streams where mangroves have not yet been planted, even though it is only present in a small percentage of these areas. The Bodo Community, Bodo Mediation Initiative (BMI), government agencies, and Shell are all involved with the remediation contractor, Shoreline Cleanup Assessment Technique (SCAT) team's monitoring and verification of the palm removal [66]. With hundreds of jobs created and some locals trained in identification and removal procedures, community engagement is indispensable. The fast regeneration of Nypa palms is one of the challenges, which also could be addressed by biocontrol experiments employing host-specific insects, as demonstrated in invasive common ragweed *Ambrosia artemisiifolia* [67] and quarterly follow-ups. To ensure long-term viability, the initiative should also incorporate public awareness efforts to discourage unintentional replanting.

RAMSAR (Wetlands) Mangrove Conservation: The Convention on Wetlands, signed in Ramsar, Iran, in 1971, under Article 1.1 defined wetland as: "Areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters"[68]. Currently, the 16 Ramsar sites in Nigeria covers about 1,077,284 ha as shown in **Table 4** [69], with 3 of the wetlands located in the Niger Delta region, namely; the Apoi Creek Forests in Bayelsa State, Upper Orashi Forests in Rivers State and Oguta Lake in Imo State located in the Niger Delta region. Interestingly, there have been new proposals to add Nun River Forest Reserve and Taylor Creek to the list [70]. The Apoi Creek Forests is a tidal freshwater swamp-forest rich in ecological and economic value. It is an important habitat for fish and home to the endangered Niger Delta Red Colobus monkey [71]. Despite being controlled by the state, the location is governed by local customs. In a study [72], it revealed that oil spills, logging, and agriculture were primary drivers of the significant mangrove degradation in Niger Delta Ramsar sites including Apoi Creek and Upper Orashi Forests, which resulted in a 3.1% loss of wetland between 1984 and 2011 and a $50M annual drop in ecological services. Weak legal enforcement, exotic species, and droughts brought on by climate change are among the difficulties. Despite their $194K/ha/year economic value, mangroves, which are essential for fisheries and erosion management, are still underappreciated. Stricter NESREA Act enforcement, community-based conservation, and remote monitoring (NDVI/GIS) to direct restoration are among the recommendations. Setting ecotourism and sustainable livelihoods as a top priority might help local resilience and prevent more harm.

Table 4: The summary of the 16 Ramsar sites in Nigeria

Ramsar (Wetland) Sites	Location in Nigeria	Coordinates	Area Coverage (ha)	Designation Date	Notable Species (Animals & Plants)
Ado-Awaye (lyake) Suspended Lake Wetland	Oyo State	07°49'19"N 03°26'17"E	165.3	01-03-2024	African mahogany, diamondback terrapin
Apoi Creek Forests	Bayelsa State	04°42'17"N 05°47'30"E	29,213	30-04-2008	Niger Delta Red Colobus monkey, mangroves, freshwater swamps
Arinta Waterfall	Southwest Geopolitical Zone	07°33'01"N 04°55'43"E	181.4	01-03-2024	Grey parrot, red nongo, kapok, African nut tree
Baturiya Wetland	Kano State	12°32'21"N 10°29'43"E	101,095	30-04-2008	Yellow-billed stork, Knob-billed goose, African Grey Hornbill
Dagona Sanctuary Lake	Yobe State	12°49'03"N 10°44'42"E	344	30-04-2008	Grey heron, Little Egret, Palaearctic waterbirds
Ebute Oni Coastal Wetland	Ijebu Waterside LGA	06°33'37"N 04°13'40"E	102.6	01-03-2024	Cross River gorilla, Sclater's guenon, Gaboon viper, raffia palm
Foge Islands	Niger & Kebbi States	10°31'08"N 04°33'50"E	4,229	30-04-2008	Western harebeest, waterbuck, hippopotamus, green monkeys

International Institute of Tropical Agriculture (IITA) Lake	Oyo State	07°29'35"N 03°54'15"E	53	01-03-2024	Ibadan maliimbe, kapok, African teak
Lake Chad Wetlands	Borno State	13°04'36"N 13°48'02"E	607,353.7	30-04-2008	Marbled Teal, indigenous fish species, grasses, sedges
Lower Kaduna-Middle Niger Floodplain	Niger & Kwara States	08°52'02"N 05°45'37"E	229,054	30-04-2008	Rosy bee-eater, Sudan-Guinea Savanna birds
Maladumba Lake	Bauchi State	10°24'N 09°51'E	1,860	30-04-2008	Grey Heron, white-necked stork, Green Fruit Pigeon
Nguru Lake (and Marma Channel)	Jigawa, Yobe	10°22'N 12°46'E	58,100	02-10-2000	Philomachus pugnax, Anas querquedula, endemic "disc Tilapia"
Oguta Lake	Imo State	05°42'13"N 06°48'03"E	572	30-04-2008	Sclater's guenon, 258 phytoplankton species, African sharptooth catfish
Osun-Oshogbo Sacred Grove	South-Western Geopolitical Zone	07°45'12"N 04°33'02"E	53.9	01-03-2024	Collared mangabey, red-bellied guenon, African sharptooth catfish, medicinal plants
Pandam and Wase Lakes	Nasarawa State	08°42'43"N 08°59'13"E	19,742	30-04-2008	White-faced Whistling Duck, West African manatee, Long-toed Lapwing
Upper Orashi Forests	Rivers State	04°53'46"N 06°31'04"E	25,165	30-04-2008	Sclater's guenon, White-throated guenon, Grey Parrot, Heslop's pygmy hippopotamus

3.3. Carbon Sequestration Potential and Climate Mitigation

Mangrove forests in the Niger Delta are blue carbon sink that can store carbon in biomass and sediment at rates far greater than those of terrestrial forests, thereby reducing the impacts of climate change. However, these ecosystems' capacity to absorb carbon has been diminished over the years by anthropogenic activities and alien species. Large-scale restoration can enhance biodiversity, increase resistance to the climate change impacts, and greatly increase carbon sequestrations.

***Quantifying Carbon Sequestration Capacity*:** Carbon sequestration in mangroves can occur through both chemical and biological mechanisms with extensive carbon cycles involving the interactions of microorganisms, plants, sediments, and fauna that work together to capture, store, and transform both organic and inorganic carbon [73]. Also, mangroves can sequester carbon through above-ground biomass such as tree trunks, leaves, and branches, and below-ground biomass such as roots and organic-rich sediments [74]. According to a study, carbon stocks in the mangrove sediments of Nigeria's Niger Delta were 194,102.24 ±53.57 Mg C, or 712,355.22 Mg CO_2, with an average of 622.12 Mg C/ha (peaty clay holding the most). Because of deterioration from illegal refining and deforestation, carbon sequestration rates were lower than global averages, at 4.54 g C/cm^2/yr. [75]. Ononyume M.O. *et al*. (2022) [76]assessed carbon stocks in Great Kwa River mangroves, Cross Rivers State Nigeria, showing that soil accounts for 89.59 %, aboveground biomass 8.41 %, belowground 1.68 %, and dead wood 0.03 % of the overall carbon density of 424.28 Mg C/ha. The average bulk density of the soil was 0.40 g/cm^3, and it had a considerable capacity to sequester carbon, storing 1,557.10 Mg/ha of CO_2 equivalent. In evaluating the aboveground carbon sequestration in freshwater swamp forests in the Niger Delta, it was shown that undisturbed forest could sequester a much higher amount of carbon at a mean value 228 t/ha when compared to transition forests at ~ 100 t/ha and damaged forests at ~104 t/ha [77]. The disturbance levels and forest base area structure were the main drivers of variations. A similar assessment [78] in Kibani, Gokana, Rivers State showed the mean sediment bulk density to be 1.30 g/cm^3 and organic carbon concentration at 12.48 % which measured the amount of carbon stored in mangrove sediments in Kibani,

while the average carbon stock was 639.80 Mg C/ha, or 947.78 Gg C (or 3,478.36 Gg CO_2). Carbon distribution was strongly impacted by sediment type and depth. These undoubtedly showed that preserving biodiversity and carbon reserves, conservation measures are essential. Compared to tropical rainforests, mangroves are far more efficient at trapping carbon because their waterlogged, oxygen-poor soils slow decomposition, allowing organic matter to accumulate over centuries [3]. Degraded mangroves in the Niger Delta might absorb a more million tons of CO_2 every year if they are fully restored, which could significantly raise Nigeria's Nationally Determined Contributions (NDCs) under the Paris Agreement. The Niger Delta's mangrove ecosystems possess exceptional carbon sequestration potential at carbon sequestration rate (CSR) of 4.54 g C/cm^2 /yr [73]. Rapid rates of carbon accumulation have been demonstrated by restoration efforts. Mangroves are emphasized as upscale nature-based climate solutions because of their better sequestrations compared to many terrestrial afforestation efforts.

***Threats Reducing Carbon Sequestration Capacity*:** Anthropogenic activities and natural forces are seriously endangering the Niger Delta mangroves' ability to sequester carbon. Since the 1950s, hundreds of oil spills have caused chronic pollution, contaminated soil and damaging root systems while interfering with microbial activities that are vital for storing carbon. The ecosystem's ability to sequester carbon has been severely compromised by these continuous threats (**Fig. 7**) and some regions have lost their initial capability to store carbon. These dangers will keep jeopardizing the Niger Delta's crucial function in regulating the climate and protecting the coast unless immediate action is taken.

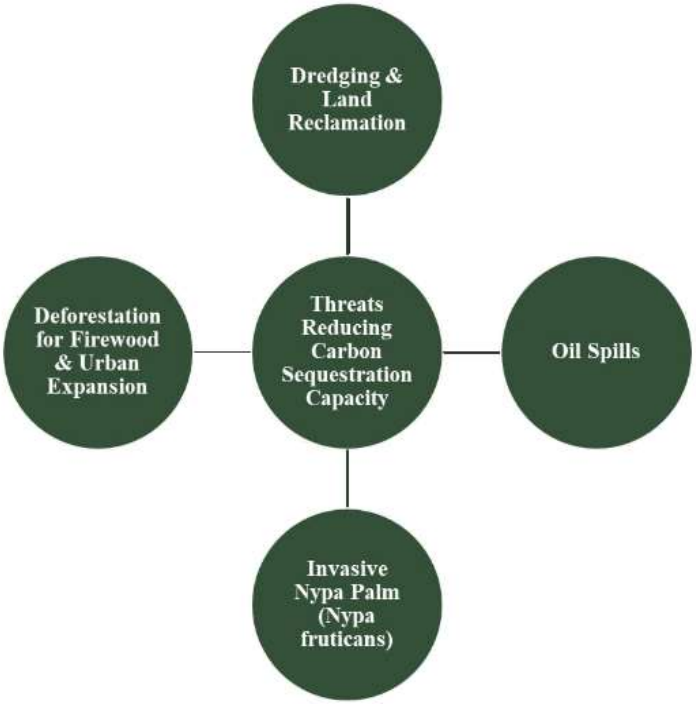

Fig. 7: Threats Reducing Carbon Sequestration Capacity

***Enhancing Carbon Sequestration through Restoration*:** Restoring damaged mangroves in the Niger Delta would substantially improve carbon sequestration using a wide range of strategies, including replanting native species such as Rhizophora racemosa and Avicennia germinans, which regenerate biomass and improve sediment carbon sequestration. Recent initiatives to restore Niger Delta mangroves yielding encouraging results in terms of carbon sequestration given the current CSR at 4.54 g C/cm^2 /yr. A recent research [5], showed that active restoration of just 30 ha may absorb 2,970 t CO_2e over 20 years, preventing 60,000 t CO^2 emissions from soil disturbance.

***Carbon Market Integration and Policy Implications*:** One realistic strategy for financing vast ecosystem restoration and climate mitigation is by integrating Niger Delta mangroves into carbon markets. These

ecosystems of mangroves are perfect candidates for blue carbon credits under voluntary and compliance markets because of their high rates of carbon sequestration, especially in biomass and soil. The recent adoption of standardized methodologies like VM0033 for tidal wetland and seagrass restoration v2.1 [79] enables credible carbon accounting, baseline establishment, and leakage assessments. Nigeria presents several strategies that can help national and international organizations reach their net-zero emission targets. Planting trees (which sequester carbon in their woody biomass and roots), implementing climate-smart agriculture, producing clean energy, and other strategies can all help achieve this. Undoubtedly, carbon trading from these strategies can have a major economic impact in addition to its beneficial impact on the environment. Initiatives like the Delta Azure Blue Carbon Project show how carbon revenue can contribute to integrated efforts such as community empowerment, biochar production, and sustainable agriculture. Frameworks for policies are changing to facilitate this integration. Access to international climate funding, especially through Article 6 of the Paris Agreement, is further strengthened by including mangrove carbon data into Nigeria's National Greenhouse Gas (GHG) Inventory. Nigeria must address the risks associated with permanency, governance, and social equity to fully reap these benefits; transparency, capacity building, and enforcement must continue to be given top priority.

3.4. Socio-Economic Impacts of Mangrove Degradation and Restoration in Nigeria

Loss of Fisheries and Livelihoods: Nigeria's artisanal and commercial fisheries depend on the fish, crabs, and shrimp that mangroves provide as breeding and nursery grounds. Fish populations have sharply decreased in in the Niger Delta mangrove region, where oil spills have severely damaged mangroves [80], [28], pushing many fishermen into poverty or engaging in illicit activities like pipeline vandalism. Women, who have historically handled and sold fish, are now more negatively impacted financially. Local fishing businesses in Lagos have been impacted by the removal of mangroves due to land reclamation such as Eko Atlantic project.

Decline in Agriculture and Food Security: People can no longer engage in profitable farming and fishing due to the destructive impacts of oil exploitation on the natural environment, crops, flora, and water. Damage to the environment destroys the inhabitants' sources of income and removes them from their ancestral lands. Environment and livelihood sustainability are bound to each other. They have serious implications on the food security of the inhabitants [81]. Due to restricted access to contemporary agricultural techniques, fishing and farming are primarily done using simple tools and conventional ways, hence low productivity.

Increased Flooding and Coastal Erosion: Recent study shows that rising floods and coastal erosion in the Niger Delta's mangrove zones are caused by a combination of changing river flow regimes, land-use changes, and climate-driven sea-level rise. Dams along the Niger River, such as Kainji and Jebba, create uncertain downstream releases, increasing the likelihood of floods and size in mangrove-rich delta plains [82]. Concurrently, coastline clearing for habitation and industry, evasive Nypa Palm species, as well as petroleum resources infrastructure weaken coastal soils, accelerating erosion. This erosion removes protecting root systems, reducing natural sediment retention and exposing populations to more severe flooding. Addressing these issues would require integrated hydrological management, mangrove recovery, and geopolitically updated flood mitigation measures.

Health Impacts from Pollution: Pollution in the Niger Delta mangroves, largely from oil spills, industrial waste, and crop residue, has serious health consequences for the inhabitants. According to current studies, continuous exposure to polluted water and air increases the risk of respiratory disorders, skin illnesses, gastrointestinal infections, and reproductive health concerns [83]. Nwankwo *et al.* (2020) highlighted that these serious health concerns could be caused by heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) in Nigeria's food chain, notably in staples like cassava, fruits, vegetables, and seafood, with the petroleum exploitations, mining, industrial activity, and inappropriate waste disposal all contributing to contamination [84]. The study underscores the need for improved monitoring by bodies such as the Standard Organization of Nigeria (SON) to reduce toxicity hazards, which include cancer, neurological illnesses, and developmental problems. Despite certain goods fulfilling safety criteria, long-term ingestion of contaminated items remains a public health hazard, necessitating prompt remediation initiatives and

increased consumer knowledge. Mangrove loss also reduces natural water filtering and food supplies, worsening hunger and waterborne infections, particularly among vulnerable populations such as children and pregnant women.

Loss of Medicinal Resources: The loss of Niger Delta mangroves no doubt could pose a severe danger to medicinal biodiversity because it destroys numerous plant species that have historically been used to heal diseases. Current study indicates that overharvesting, oil pollution, and coastal expansion are quickly destroying these habitats [85], resulting in a decrease in species such as Rhizophora and Avicennia, which have antibacterial and anti-inflammatory capabilities [86], [87]. The inhabitants rely largely on mangrove plants for basic healthcare. Without immediate conservation and sustainable management, the region risks losing vital ethnomedicinal knowledge and resources needed for traditional treatment and pharmaceutical research.

Tourism and Cultural Impacts: Tourism and cultural influences on the Niger Delta mangroves are becoming more prominent, with ecotourism providing opportunities for sustainable living but also creating challenges if not managed effectively. Unmanaged tourism may cause environmental deterioration, pollution, and wildlife disturbance. Community-based ecotourism programs, such as those in the Andoni Island region, offer potential in terms of conservation awareness and money generation for local inhabitants. Many indigenous people place spiritual and cultural importance in mangroves, which are used in ceremonies and healing. The preservation of these habitats is critical to the Niger Delta's ecological sustainability and cultural heritage.

See the **Table 5, 6, 7, 8, and 9 for** the **s**ummary of the socio-economic impacts of mangrove degradation, socio-economic benefits of mangrove restoration, equity gaps in restoration, statistical analysis of socio-economic drivers

Table 5: Summary of the Socio-Economic Impacts of Mangrove Degradation

Factor	Key Findings	Biodiversity Linkage	Ref
Fisheries Collapse	Fish populations declined by 40–60% in oil-spill zones; 500K fishermen displaced.	Loss of nursery habitats for fish/shrimp reduces aquatic biodiversity.	[28], [75], [78]
Agricultural Decline	Soil contamination reduced crop yields by 30–50%; cassava Pb levels 10× WHO limits.	Heavy metals bioaccumulate, affecting flora/fauna and food chains.	[81], [84]
Flooding & Erosion	Coastal erosion increased by 15% (1996–2020); 12 villages relocated in Bayelsa.	Mangrove loss removes natural buffers, exacerbating habitat fragmentation.	[82], [88]
Health Impacts	Respiratory/skin diseases rose 25% in polluted zones; benzene levels 900× WHO.	Pollution kills microbial communities critical for nutrient cycling.	[11], [83]
Medicinal Loss	60% decline in *Rhizophora* spp. (anti-inflammatory uses).	Biodiversity loss erodes ethnobotanical knowledge.	[15], [24], [85]
Cultural Erosion	8 sacred mangrove sites degraded; Ogoni rituals disrupted.	Spiritual species (e.g., Grey Parrot) face extinction.	[48],

Table 6: Socio-Economic Benefits of Mangrove Restoration

Initiative	Intervention	Socio-Economic Outcomes	Biodiversity Co-Benefits
NDMRP (Akwa Ibom)	Planted 100K trees; engaged 5K fishermen.	Increased fish catches by 35%; created 300 jobs for women.	Native mangrove recovery boosted crab/fish diversity.
DeltaAzure Program	520K ha restored biochar production.	$12M carbon revenue; 135 communities trained in sustainable aquaculture.	Seagrass revival improved marine habitat connectivity.
Lokiaka Women's Network	Women-led nurseries; honey/ecotourism.	200 women earned $50/month; 40 km² restored.	Reintroduced *Avicennia* spp. enhanced pollinator habitats.
UN-REDD (Cross River)	Nypa eradication; cassava farming.	540 households diversified incomes; fish stocks rebounded by 20%.	Native mangroves regrew, attracting migratory birds.
Shell's Bodo Cleanup	£55M settlement; manual Nypa removal.	1,000 jobs created; 2028 target for full remediation.	Oil-degrading microbes revived soil biodiversity.

Table 7: Equity Gaps in Restoration

Challenge	Socio-Economic Dimension	Biodiversity Impact	Policy Recommendations
Funding Shortfalls	Only 30% of NDMRP's $50K budget secured.	Limited scale of species reintroduction.	Leverage blue carbon credits (VM0033).
Gender Inequality	Women excluded from 60% of paid restoration jobs.	Loss of traditional knowledge on medicinal plants.	Mandate gender quotas in NGO/government projects.
Land-Use Conflicts	Eko Atlantic project displaced 10K fishers (Lagos).	Mangrove fragmentation reduced bird nesting sites.	Enforce Free, Prior, and Informed Consent (FPIC) for developers.
Climate Vulnerability	Sea-level rise threatens 30% of Delta's rice farms.	Salinity stress reduces mangrove genetic diversity.	Promote salt-tolerant species (e.g., *Avicennia marina*).

Table 8: Statistical Analysis of Socio-Economic Drivers

Variable	Analysis Method	Result	Implication
Oil Spills vs. Poverty	Pearson's correlation (N=14,053 spills).	*r* = 0.82 ($p < 0.001$) between spills and fishery collapse.	Confirms pollution as a primary livelihood threat.
Restoration vs. Jobs	Linear regression (DeltaAzure data).	1 ha restored = 0.5 jobs ($R^2 = 0.91$).	Quantifies employment potential.
Gender Inclusion	Chi-square test (Lokiaka vs. govt. projects).	Women-led projects had 30% higher survival rates ($\chi^2 = 15.6$, $p < 0.01$).	Supports gender-inclusive conservation.
Carbon Revenue	Cost-benefit analysis (VM0033 methodology).	$120/ha/year from carbon credits vs. $80/ha fishing.	Incentivizes mangrove protection over exploitation.

Table 9: Key Statistical Analyses for Biodiversity Conservation

Analysis	Method	Result	Significance
Species Diversity vs. Oil Spills	Regression analysis of spill density vs. mangrove health.	Negative correlation ($R^2 = 0.78$, $p < 0.01$).	Quantifies pollution's impact on biodiversity.
Nypa Invasion Rate	Satellite NDVI time-series (2015–2025).	12% annual expansion rate.	Urgency for eradication programs.
Carbon-Biodiversity Link	ANOVA of carbon stocks in intact vs. degraded sites.	Intact sites store 2.3× more carbon ($p < 0.001$).	Supports "blue carbon" as a biodiversity proxy.
Community-Led Survival Rates	Field surveys of Lokiaka vs. government projects.	Community projects: 80% survival vs. 50% (government).	Highlights traditional knowledge efficacy.

3.5. Challenges and Strategic Recommendations for Sustainable Restoration

Deforestation, pollution, overfishing, and climate change are some of the issues that the Niger Delta mangroves must deal with. Stringent regulations, community and stakeholder engagement, pollution prevention, alternative livelihoods, climate-resilient species, and more public knowledge are all necessary for sustainable restoration. To restore biodiversity, safeguard livelihoods, and guarantee long-term ecological resilience, cooperation and sufficient finance are crucial. **Table 10** shows the strategic recommendations to these challenges.

Table 10: Challenges and Strategic Recommendations for Sustainable Restoration

Challenges	Strategic Recommendations
Deforestation due to oil exploration and pipeline construction	Enforce strict environmental regulations and implement eco-friendly extraction methods and enforce stringent environmental standards.
Pollution from oil spills and industrial waste	Strengthening monitoring and rapid response systems for spill cleanups; hold polluters accountable
Overharvesting of mangroves for fuelwood and timber	Promote alternative livelihoods and energy sources; enforce sustainable harvesting practices
Unregulated aquaculture and land conversion	Implement zoning laws; promote sustainable aquaculture practices
Loss of biodiversity and ecosystem services	Restore degraded habitats; reintroduce native mangrove species
Community exclusion from conservation processes	Encourage community-based management and indigenous knowledge integration
Climate change impacts such as sea level rise and salinity	Develop adaptive restoration strategies; use climate-resilient mangrove species
Weak institutional and policy frameworks	Strengthening governance, policy implementation, and inter-agency collaboration
Lack of funding and technical capacity	Secure international and local funding; build local restoration expertise
Low public awareness and education on mangrove value	Launch awareness campaigns; integrate mangrove education into school curricula

4. CONCLUSIONS

Restoring decades of ecological degradation, achieving climate mitigation targets, and protecting the livelihoods of disadvantaged communities all depend on the restoration of mangrove ecosystems in the Niger Delta. According to the review's findings, restoring mangroves not only strengthens coastal resilience and restores biodiversity, it also provides a cost-effective means to capture carbon at rates greater than many terrestrial forests. Considering the region's promise, several obstacles still exist, mostly related to invasive species, oil pollution, a lack of funding, and a lack of institutional assistance. High ecological and socio-economic returns may be obtained via interactive restoration strategies, as demonstrated by the incorporation of community-led approaches such as those seen in Ogoniland and the DeltaAzure Program. Other avenues for scaling up activities include carbon market structures and policy alignment with international climate guidelines. An extensive, multi-sectoral strategy that combines research, community knowledge, and policy enforcement is necessary for restoration projects to be successful. Investments in education, gender inclusion, and climate-resilient livelihoods further ensure that gains are equitable and sustainable. In the end, the Niger Delta mangroves can operate as a globally paradigm for nature-based climate action if they are preserved and restored. They can provide a model for resilience, sustainability, and carbon-neutral growth in coastal areas that are threatened in a similar way.

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