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Blue Carbon Stocks, Nutrient Dynamics, and Ecosystem Health in Niger Delta Mangrove Wetlands

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ABSTRACT

Mangrove wetlands of the Niger Delta are among the largest blue-carbon ecosystems in Africa, yet oil pollution and the spread of the invasive palm Nypa fruticans are changing what they store and how they function. This study examined blue carbon stocks, nutrient dynamics, and ecosystem health across three stand conditions in Rivers and Bayelsa States: intact Rhizophora-dominated mangrove at Buguma Creek, oil-impacted mangrove at Bodo Creek, and Nypa-invaded fringe along the Brass, St Nicholas River. Twelve 10 m × 10 m plots (four per condition) were sampled in the dry and wet seasons of 2025. Vegetation structure, pore-water chemistry, and sediment cores to 100 cm were analyzed for bulk density, organic carbon, total nitrogen, and total phosphorus. Ecosystem carbon was estimated from sediment and biomass pools, and a composite health index was computed from canopy, regeneration, native dominance, dissolved oxygen, and bare ground. Intact stands stored 812 ± 64 Mg C ha^{-1}, oil-impacted stands 446 ± 51 Mg C ha^{-1}, and Nypa stands 304 ± 38 Mg C ha^{-1}. Sediment held 80, 88% of the stock. One-way ANOVA showed a significant condition effect on sediment carbon, $F(2, 9) = 82.7$, $p < .001$. Oil-impacted plots had elevated ammonium and total nitrogen, depressed dissolved oxygen, and poor seedling recruitment. Nypa plots were nutrient-poorer and structurally simplified. Sediment organic carbon was strongly correlated with the health index ($r = .86$, $p < .001$). The study concludes that degradation is already a carbon and nutrient problem, and that protecting remaining Rhizophora stands is the highest- return action for both ecosystem health and climate mitigation.

Keywords: *blue carbon, mangrove, Niger Delta, Nypa fruticans, oil pollution, nutrient dynamics, ecosystem health, Rhizophora racemosa*

Introduction Mangroves occupy the intertidal edge between land and sea. They trap sediment, nurse fish, damp storm surge and, more recently in climate policy, store carbon at rates that few terrestrial forests match. Most of that carbon is not in the trunks. It is in the wet, anoxic mud, where litter and root tissue decay slowly and can remain for centuries (Donato et al., 2011; Alongi, 2014). The term blue carbon names this coastal store, and the emissions that follow if the store is drained, dug, or killed (Mcleod et al., 2011; Howard et al., 2014).

Nigeria holds the largest mangrove estate in Africa and about the fifth largest in the world. A 2023 national assessment placed mangrove cover at 957,747 ha, of which about 90% lies in Delta, Bayelsa, and Rivers States, the core of the Niger Delta (Barenblitt et al., 2026). The dominant trees are red mangroves of the genus Rhizophora, especially Rhizophora racemosa, with Rhizophora harrisonii, Rhizophora mangle, Avicennia germinans, and Laguncularia racemosa on the landward and creek margins. The forest is not intact. From 1990 to 2023, Nigeria lost about 4.5% of mangrove area. Oil spills were the direct cause of at least 37% of ecosystem loss in the Delta, and by 2023 almost 10% of the national mangrove area, some 93,178 ha, was dominated by the invasive mangrove palm Nypa fruticans, which expanded by about 70,000 ha in 15 years (Barenblitt et al., 2026). Conversion over 1995, 2023 was estimated to have emitted 48.62 Tg CO_2-equivalent.

Local carbon work already shows both the size of the store and its sensitivity. Sediments in the eastern Niger Delta are peaty clays with a mean bulk density near 1.30 g cm^{-3} and organic carbon often above 10%, and plot-scale stocks in the Bodo forest have been reported from 414 to 972 Mg C ha^{-1}, with 78, 94% in the soil (Nwankwo et al., 2023; Oguns et al., 2025). Interior, less disturbed basin stands hold more; oiled and opened stands hold less. What is still thin is a single comparative account that places carbon, nutrients, and a health score

side by side across the two pressures that now define the Delta: chronic oiling and nypa replacement. Carbon lost from a dead Rhizophora stand is not automatically replaced by a palm thicket. Nutrients released from oiled detritus do not automatically support regeneration. This study treats those three outcomes together.

Statement of the Problem The Niger Delta mangroves are asked to do two jobs at once. It is a fishery and storm buffer for creek communities, and it is a carbon asset in Nigeria's climate accounts. Both jobs fail when the forest is oiled or replaced. The United Nations Environment Programme's assessment of Ogoniland documented widespread hydrocarbon contamination of sediments, groundwater and creeks, and recommended a recovery measured in decades rather than seasons (UNEP, 2011). Nypa, introduced in the twentieth century and now dominant on many estuary fringes, forms dense monospecific stands that shade out mangrove seedlings and provide poorer habitat for the crabs and fish that maintain tidal channels.

Despite this, management still leans on area totals. A hectare of nypa and a hectare of mature Rhizophora are not equivalent in carbon, in nutrient retention, or in the capacity to recover after a spill. Without condition-specific stocks and a health reading tied to those stocks, restoration targets and any future blue-carbon claim will rest on a national mean that the degraded stands cannot meet.

The problem of this study is therefore: how do blue carbon stocks, nutrient status and ecosystem health differ among intact, oil-impacted and nypa-invaded mangrove wetlands of the Niger Delta, and what does that difference imply for protection and restoration?

Purpose of the Study The general purpose of the study was to assess blue carbon stocks, nutrient dynamics and ecosystem health in Niger Delta mangrove wetlands under contrasting stand conditions. Specifically, the study sought to:

1. estimate above-ground, below-ground and sediment blue carbon stocks in intact, oilimpacted and Nypa-invaded stands;

2. compare sediment and pore-water nutrient status across the three conditions and between seasons;

3. assess ecosystem health using structural and water-quality indicators; and

4. examine the relationship between sediment organic carbon and ecosystem health.

RESEARCH QUESTIONS

1. What are the blue carbon stocks of intact, oil-impacted and Nypa-invaded mangrove stands?

2. How do nitrogen, phosphorus and pore-water nutrients differ among stand conditions?

3. What is the ecosystem health status of the three stand conditions?

4. Is sediment organic carbon related to ecosystem health?

Hypotheses The following null hypotheses were tested at the .05 level of significance:

1. H_{01}: There is no significant difference in sediment blue carbon stock among intact, oilimpacted and Nypa-invaded stands.

2. H_{02}: There is no significant relationship between sediment organic carbon and the ecosystem health index.

Significance of the Study The findings give the Federal Ministry of Environment, the National Council on Climate Change, and state environment ministries in Rivers and Bayelsa a condition-specific carbon range rather than a single national factor. They give the Hydrocarbon Pollution Remediation Project and community restoration schemes a reason to treat native Rhizophora recovery, not mere green cover, as the success test. Creek fisheries and disaster-risk planning benefit from a health score that links seedling failure and low dissolved oxygen to the same plots that have already lost carbon.

Researchers gain a baseline for repeating the contrast after remediation or nypa removal.

Review of Related Literature Conceptual Review Blue carbon. Blue carbon is the organic carbon captured and stored by coastal vegetated ecosystems, principally mangroves, saltmarshes and seagrasses (Mcleod et al., 2011). In mangroves the sediment pool commonly exceeds the biomass pool because tidal import, high root production and anoxic decay allow burial (Donato et al., 2011; Alongi, 2014). A stock is not a flux. A stand can hold a large store and still be a weak annual sink if degradation has stopped new burial, or a strong source if the store is exposed.

Nutrient dynamics. Nitrogen and phosphorus enter mangrove mud from litter, roots, tidal water and, in the Delta, from settlements and spilled hydrocarbons. Intact stands typically conserve nitrogen in biomass and peat and release it slowly. Disturbed stands can show a pulse of ammonium from dead tissue, a drop in nitrate where oxygen is scarce, and a shift in N:P that favours algal films over seedlings. Nutrient status is therefore both a fertility measure and a stress signal.

Ecosystem health. Health, as used here, is the capacity of the stand to maintain native structure, regenerate, and keep creek water oxygenated. It is not a claim of pristine wilderness. A healthy Niger Delta stand in this study is one still dominated by Rhizophora, with a closed canopy, a seedling bank, limited bare mud and dissolved oxygen sufficient for creek fauna. Nypa cover and oil-bared ground lower that score even when the site is still mapped as mangrove.

Theoretical Framework The study is anchored on the blue-carbon stock-and-flux framework of Mcleod et al. (2011) and the mangrove carbon-cycling synthesis of Alongi (2014). The framework separates storage in biomass and sediment from the lateral and gaseous fluxes that change that storage. It predicts that activities which kill trees and aerate or erode peat, spills, channelisation, cutting , will reduce stocks and can reverse the sink. It also predicts that a structural replacement which produces less woody biomass and less refractory peat, such as nypa for Rhizophora, will lower the long-term store even if green cover returns.

The study is also informed by press-and-pulse disturbance theory. An oil spill is a pulse: a short, intense kill of roots, seedlings and infauna. Chronic re-oiling, contaminated groundwater and nypa occupation are presses: persistent conditions that block return to the pre-disturbance state (UNEP, 2011). The theory explains why a creek can remain green and still fail as a carbon and fishery system. Recovery requires removal of the press, not only the end of the pulse.

Empirical Review Global syntheses place mangroves among the most carbon-rich tropical forests, with ecosystem stocks commonly several hundred to more than a thousand megagrams of carbon per hectare, the majority below ground (Donato et al., 2011; Kauffman & Donato, 2012). IPCC wetland guidance therefore treats mangrove soil as a distinct pool that national inventories should not ignore (IPCC, 2014).

Niger Delta measurements agree on the size of the pool and on its spatial unevenness. Nwankwo et al. (2023) reported eastern Delta sediments with bulk density from 0.95 to 1.97 g cm^{-3} (mean 1.30) and organic carbon from 0.9% to 33.6% (mean 12.48%), and a study-area stock equivalent to about 732,596 Mg CO_2 in the sediment pool they surveyed. Oguns et al. (2025), working in the Bodo forest, found total ecosystem stocks of 414, 972 Mg C ha^{-1}, 78, 94% in soils, highest in interior basin zones and depleted where historical spills had opened the canopy. Species dominance, tidal frequency and soil texture structured the pattern; Rhizophora racemosa marked the high-stock stands.

The loss side is now quantified at national scale. Barenblitt et al. (2026) attributed at least 37% of mangrove ecosystem loss in the Niger Delta directly to oil spills, and documented nypa dominance on 93,178 ha. Nypa does not reproduce the prop-root architecture, peat depth or fisheries function of Rhizophora outside its native Asian range. UNEP (2011) had already shown that hydrocarbon contamination in Ogoniland was deep, widespread and slow to attenuate. Together these studies imply that carbon accounting which uses an intact-stand factor on a nypa or oiled hectare will overstate the asset.

Summary of Literature Review The literature establishes that Niger Delta mangroves are large blue-carbon systems, that oil and nypa are the principal degraders, and that soil holds most of the carbon. It does not yet set

nutrient status and a health score on the same plots as the carbon stock. That joint account is the gap this study fills.

Methodology Research design. The study used a comparative field design with three stand conditions as the fixed factor. Conditions were not manipulated. Dry-season (February) and wet-season (July) sampling in 2025 captured the main hydrological contrast.

Area of the study. Work was carried out in tidal mangrove wetlands of the eastern and central Niger Delta. Three creeks were selected to represent the conditions of interest. Buguma Creek, Asari-Toru Local Government Area, Rivers State, was the intact reference: a Rhizophora racemosa basin stand with no recorded major spill in the decade before sampling. Bodo Creek, Gokana Local Government Area, Rivers State, was the oil-impacted condition, within the wider Ogoniland contamination field described by UNEP (2011) and later carbon work (Oguns et al., 2025). The Brass, St Nicholas River fringe, Brass Local Government Area, Bayelsa State, was the Nypainvaded condition, with palm dominance on the estuary edge and residual red mangrove in the interior.

Sampling. Four plots of 10 m × 10 m were laid in each condition, at least 150 m apart and at similar intertidal elevation (n = 12). In each plot all woody stems were identified, counted and measured for diameter at breast height, or above the highest prop root for Rhizophora. Canopy cover, bare ground and nypa cover were estimated with a spherical densiometer and line intercept.

Seedlings were counted in five 1 m × 1 m quadrats. Three sediment cores per plot were taken to 100 cm with a gouge auger and sectioned at 0, 15, 15, 30, 30, 50 and 50, 100 cm. Pore water was drawn at 20 cm. Surface-water dissolved oxygen, salinity, temperature and pH were read in situ with a calibrated multiparameter probe at ebb tide.

Laboratory analysis. Bulk density was determined from oven-dry mass and core volume. Organic carbon was determined by the Walkley, Black wet-oxidation method, total nitrogen by Kjeldahl digestion, and total phosphorus by perchloric digestion and colorimetry. Pore-water ammonium, nitrate and phosphate were determined by standard spectrophotometric methods. Biomass was estimated with pantropical mangrove allometries, converted to carbon with factors of 0.48 for above-ground wood and 0.39 for roots, following Kauffman and Donato (2012). Sediment carbon stock for each interval was computed as bulk density × carbon concentration × thickness, summed to 100 cm and expressed in Mg C ha^{-1}. Carbon dioxide equivalent used the factor 3.67.

Ecosystem health index. A plot index from 0 to 1 was the unweighted mean of five normalised scores: canopy cover, mangrove seedling density, relative dominance of native Rhizophora, dissolved oxygen, and the complement of bare ground plus nypa cover. The index is a study construct for comparison, not a statutory standard.

Data analysis. Means and standard deviations described each condition. One-way analysis of variance tested H_{01}, with Tukey's HSD for pairwise contrasts. Pearson's correlation tested H_{02}.

Significance was set at .05. Seasons were compared with paired tests on plot means; where the season effect was small relative to condition, seasonal values were pooled and the season term reported.

Results Research Question 1: Blue carbon stocks Table 1. Vegetation structure by stand condition (plot means ± SD, n = 4)

Variable Intact (Buguma) Oil-impacted (Bodo) Nypa (Brass) Pattern Stem density (ha^{-1}) 1,840 ± 210 620 ± 140 410 ± 90 Intact highest Mean DBH (cm) 14.6 ± 2.1 8.1 ± 1.4 6.4 ± 1.2 Intact highest Canopy cover (%) 78 ± 6 31 ± 8 64 ± 7 Palm canopy at Brass Variable Intact (Buguma) Oil-impacted (Bodo) Nypa (Brass) Pattern Seedlings (m^{-2}) 4.8 ± 1.1 0.9 ± 0.4 0.4 ± 0.2 Recruitment collapse Nypa cover (%) 3 ± 2 18 ± 6 81 ± 7 Brass replaced Bare ground (%) 6 ± 2 41 ± 9 12 ± 4 Bodo opened Note. Stem density at Brass counts residual woody mangrove, not palm clumps. DBH = diameter at breast height.

Table 1 shows the vegetation structure across stand conditions.

The table revealed that intact mangrove (Buguma) shows the healthiest forest structure, recording the highest stem density (1.840 210 ha-1), largest mean DBH (14.6 2.1cm) and density canopy cover (78 5%).

Sever oil impact (Bodo) causes a drastic decline in both stem density (620 140 ha-1) and canopy cover (31 8%) compared to pristine stand. Nypa invaded stand (Brass) exhibits the lowest stem density (410 90 ha -1) and smallest tree diameter (6.4 1.2cm), though palm growth maintains moderate canopy coverage (64 7%).

Disturbance significantly degrades mangrove structure; Oil pollution severely depletes forest canopy, While Nypa palm invasion replaces original tree density with smaller , diameter growth.

Seedling recruitment and ground cover ; seedling density undergoes a dramatic 'recruitment collapse' in stressed environments, dropping from 4.8 1.1m-2 in intact forest to 0.9 0.4m-2 in oil-impacted area and 0.4 0.4m-2 in Nypa , invaded plots. This indicates a systematic failure of natural forest self , replacement.

Habitat disturbance indicators; Nypa cover peaks aggressively at 81 7% in brass (replacing nature species"), while oil impacted bodo shows high exposure with bare ground reaching 41 9%.

Table 2. Carbon pools by stand condition (Mg C ha⁻¹, mean ± SD, n = 4 plots)

Pool	Intact (Buguma)	Oil-impacted (Bodo)	Nypa (Brass)	Soil share
Above-ground biomass	112 ± 18	52 ± 11	22 ± 6	,
Below-ground biomass	52 ± 9	32 ± 7	14 ± 4	,
Sediment, 0, 100 cm	648 ± 54	362 ± 41	268 ± 33	80, 88%
Total ecosystem stock	812 ± 64	446 ± 51	304 ± 38	,
CO2 equivalent	2,980 ± 235	1,637 ± 187	1,116 ± 139	× 3.67

Pool Intact (Buguma) Oil-impacted (Bodo) Nypa (Brass) Soil share Above-ground biomass 112 ± 18 52 ± 11 22 ± 6 , Below-ground biomass 52 ± 9 32 ± 7 14 ± 4 , Sediment, 0, 100 cm 648 ± 54 362 ± 41 268 ± 33 80, 88% Total ecosystem stock 812 ± 64 446 ± 51 304 ± 38 , CO_2 equivalent 2,980 ± 235 1,637 ± 187 1,116 ± 139 × 3.67 Note. Sediment stock is the sum of 0, 15, 15, 30, 30, 50 and 50, 100 cm intervals. CO_2 equivalent = carbon × 3.67.

Table 2 shows that intact Buguma stands stored 812 Mg C ha^{-1}, against 446 at oiled Bodo and 304 under nypa at Brass. Sediment held 80% of the intact stock, 81% of the oiled stock and 88% of the nypa stock. The absolute sediment gap between Buguma and Brass was 380 Mg C ha^{-1}, equivalent to about 1,395 Mg CO_2 ha^{-1} no longer held in the top metre. Organic carbon concentration declined with depth in all conditions, but the decline was steepest at Bodo, where the 0, 15 cm layer was carbon-poor relative to Buguma and the deeper peat was patchy. Bulk density was lowest in intact peaty clay (mean 0.98 g cm^{-3} in the surface) and highest in oiled, compacted surface mud (mean

1.36 g cm^{-3}).

Research Question 2: Nutrient dynamics Table 3. Sediment and pore-water nutrients by stand condition (plot means ± SD)

Variable Intact (Buguma) Oil-impacted (Bodo) Nypa (Brass)

Sediment total N, 0, 15 cm (%) 0.42 ± 0.06 0.61 ± 0.09 0.28 ± 0.05 Sediment total P, 0, 15 cm (%) 0.08 ± 0.01 0.11 ± 0.02 0.06 ± 0.01 Pore-water NH_4^+ (mg L^{-1}) 1.8 ± 0.4 4.6 ± 0.9 1.1 ± 0.3 Pore-water NO_3^- (mg L^{-1}) 0.21 ± 0.05 0.08 ± 0.03 0.14 ± 0.04 Pore-water PO_4^{3-} (mg L^{-1}) 0.09 ± 0.02 0.16 ± 0.04 0.07 ± 0.02 Dissolved oxygen (mg L^{-1}) 5.4 ± 0.6 2.1 ± 0.5 4.2 ± 0.5 Salinity (psu) 18.2 ± 1.4 16.4 ± 1.8 12.1 ± 1.6 pH 6.8 ± 0.2 6.1 ± 0.3 6.5 ± 0.2 Note. Dissolved oxygen, salinity and pH are ebb-tide surface readings. Nutrient values are dry- and wet-season plot means pooled; wet-season phosphate was higher at all sites, but condition rank did not change.

Table 3 shows two different nutrient failures. Bodo was enriched and oxygen-poor: total nitrogen and ammonium were more than double the intact means, nitrate was depressed, and dissolved oxygen averaged 2.1 mg L^{-1}. That pattern fits a pulse of organic nitrogen from dead roots and oiled detritus under low redox. Brass was dilute: lower total nitrogen, lower phosphorus and lower salinity, consistent with a palm stand that builds less peat and sits on a more river-influenced fringe.

Buguma held intermediate nutrients with the highest nitrate and oxygen, the signature of a stand that is processing nitrogen rather than accumulating it as ammonium.

Research Question 3: Ecosystem health Table 4. Ecosystem health index and component scores (0, 1, plot means)

Component Intact (Buguma) Oil-impacted (Bodo) Nypa (Brass)

Canopy 0.78 0.31 0.64 Seedling density 0.86 0.18 0.09 Native Rhizophora dominance 0.91 0.44 0.16 Dissolved oxygen 0.77 0.30 0.60 Intact ground (low bare/nypa) 0.91 0.41 0.12 Health index 0.85 0.33 0.32 Note. Index is the unweighted mean of the five component scores. Brass scores higher on canopy than Bodo because palm fronds close the cover, but fails on native dominance and seedlings.

Table 4 shows that Buguma was in good condition for this index (0.85). Bodo and Brass scored almost equally poorly (0.33 and 0.32), for different reasons. Bodo failed on canopy, oxygen and bare ground. Brass failed on seedlings and native dominance, despite a palm canopy that would look healthy in a coarse greenness map. Health and greenness are therefore not interchangeable in this wetland.

Hypothesis tests Table 5. One-way ANOVA of sediment carbon stock (0, 100 cm) among stand conditions Source df SS MS F P Condition 2 313,376 156,688 82.7 < .001 Error 9 17,058 1,895 Total 11 330,434 Note. Tukey HSD: Buguma > Bodo > Brass, all pairs $p < .05$. H_{01} rejected.

Table 6. Pearson correlation of sediment organic carbon with the health index (n = 12 plots)

Pair	r	p	Decision
Sediment C (Mg C ha-1) × health index	.86	< .001	H02 rejected

Pair R p Decision Sediment C (Mg C ha^{-1}) × health index .86 < .001 H_{02} rejected Note. The association is cross-sectional. It does not by itself prove that health loss caused the carbon loss.

Table 5 shows $F(2, 9) = 82.7$, $p < .001$. H_{01} was rejected. Intact sediment held significantly more carbon than oiled sediment, which held significantly more than nypa sediment. Table 6 shows $r = .86$, $p < .001$. H_{02} was rejected. Plots with higher health scores held more sediment carbon. The two degraded conditions converged on poor health while remaining distinct in carbon, which is why the correlation is strong but not perfect.

Discussion of Findings Blue carbon stocks. Intact stands at Buguma stored 812 Mg C ha^{-1}, inside the upper half of the 414, 972 Mg C ha^{-1} range reported for Bodo by Oguns et al. (2025), and consistent with the high organic-carbon peats described for the eastern Delta by Nwankwo et al. (2023). Oiled Bodo plots, at 446 Mg C ha^{-1}, sat at the bottom of that published range. Nypa plots at Brass, at 304 Mg C ha^{-1}, fell below it. The ranking matches the blue-carbon prediction that killing trees and replacing a peatbuilding species reduces the store (Alongi, 2014; Mcleod et al., 2011). Soil dominance of 80, 88% also matches Donato et al. (2011) and the Bodo finding that soils hold 78, 94% of ecosystem carbon.

The management implication is sharp: a restoration that plants or merely greens the surface, without recovering peat and native root mats, recovers the smaller pool.

Nutrient dynamics. The oiled creek was not nutrient-poor. It was ammonium-rich and oxygenpoor, with nitrate suppressed. That is a decomposition and redox signal, not a fertility advantage.

Seedlings do not recruit on anoxic, ammonium-loaded, hydrocarbon-stressed mud, which is why Bodo combined high total nitrogen with 0.9 seedlings m^{-2}. UNEP (2011) described contamination deep enough to keep this press

in place after the original spills. The nypa fringe showed the other failure: lower nitrogen, lower phosphorus and lower salinity, a stand that neither builds the peat nutrient capital of Rhizophora nor occupies the same tidal position. Wet-season phosphate rose everywhere, but it did not reorder the conditions. Season modulates the numbers; condition sets them.

Ecosystem health. Equal health scores at Bodo and Brass hide different mechanisms, which is why the index was reported with its components. Oil opens the canopy, bares the mud and strips oxygen.

Nypa closes the canopy with the wrong species and stops native regeneration. A satellite greenness product would rank Brass above Bodo and could rank Brass close to Buguma. The field index does not. This supports the remote-sensing caution that nypa is difficult to separate from native mangrove and that area totals conceal ecosystem-service loss (Barenblitt et al., 2026). Health, on this evidence, is native structure plus regeneration plus oxygen, not cover alone.

Carbon and health. The correlation of .86 links the climate asset to the ecological one. Plots that still function as Rhizophora forest still hold the carbon. Plots that have been oiled or replaced hold less. The design cannot assign cause in a single year: carbon may have been lost because the stand died, and the stand may fail to recover because the peat and chemistry have changed. Press-andpulse theory allows both. For policy the direction is enough. Protecting the remaining high-health stands avoids a loss of several hundred megagrams of carbon per hectare, while remediation and nypa control are attempts to rebuild a store that the degraded plots no longer have.

Conclusion Blue carbon, nutrients and ecosystem health in these Niger Delta wetlands move together, and they move downward under both oil and nypa. Intact Rhizophora stands at Buguma stored 812 Mg C ha^{-1}, most of it in the top metre of sediment, and scored 0.85 on the health index. Oil-impacted Bodo stored 446 Mg C ha^{-1}, with elevated ammonium, low oxygen and a failed seedling bank.

Nypa-invaded Brass stored 304 Mg C ha^{-1} and had lost native dominance. The three conditions differed significantly in sediment carbon, and carbon tracked health. Treating every green hectare as an intact mangrove will overstate Nigeria’s blue-carbon asset and understate the restoration task.

The standing forest is the mitigation measure. The degraded forest is a recovery project measured in peat and seedlings, not in canopy colour.

RECOMMENDATIONS

1. The National Council on Climate Change and the Federal Ministry of Environment should report Niger Delta mangrove carbon by condition class , intact Rhizophora, oil-impacted, and nypa-dominated , rather than by a single area factor.

2. Remaining high-health stands, of the Buguma type, should be prioritised for protection.

Avoided loss from an 812 Mg C ha^{-1} stand is larger and more certain than expected gain from a 304 Mg C ha^{-1} palm fringe.

3. Hydrocarbon Pollution Remediation Project clean-up in creeks such as Bodo should be judged by dissolved oxygen, seedling density and native canopy, not only by hydrocarbon concentration. Ammonium-rich, anoxic mud will not grow a carbon stock.

4. Nypa control on estuary fringes should be paired with Rhizophora planting only where salinity, elevation and substrate still suit red mangrove. Palm removal without hydrology is a clearance, not a restoration.

5. Community monitors in Rivers and Bayelsa should be equipped to record seedling density, bare ground and nypa cover alongside spill reports, so health decline is seen before the next carbon survey.

6. Any blue-carbon transaction should use conservative, condition-specific factors and a permanence buffer for spill and invasion risk. A credit written on an intact-stand factor and delivered on a nypa hectare is not a real emission reduction.

Implications for Climate and Coastal Livelihoods The gap between Buguma and Brass, 508 Mg C ha^{-1} in total ecosystem stock, is the climate cost of replacement. Scaled across the 93,178 ha already reported as nypa-dominated, even a fraction of that gap is material beside Nigeria's mitigation goals. The same plots that have lost carbon have lost the prop-root habitat and the oxygenated creek water on which fisheries depend. Blue carbon policy that ignores health will pay for hectares. Coastal policy that ignores carbon will miss the climate argument for a protection that fishers already need. The two are one wetland.

Limitations and Suggestions for Further Studies The study covered 12 plots in three creeks and one year. It does not represent the western Delta, and it did not measure methane or lateral carbon export, so the stock contrast is not a full net-flux account. Hydrocarbon concentrations were not assayed in this design; oil impact was inferred from site history, bare ground, redox and nutrients. Further work should add ^{210}Pb or ^{14}C burial rates, total petroleum hydrocarbons, a western Delta reference, and a repeat survey after remediation and nypa removal, so that recovery of health can be tested as a recovery of carbon rather than assumed.

References Alongi, D. M. (2014). Carbon cycling and storage in mangrove forests. Annual Review of Marine Science, 6, 195, 219. https://doi.org/10.1146/annurev-marine-010213-135020 Barenblitt, A., Fatoyinbo, L., Thomas, N., Stovall, A., de Sousa, C., Nwobi, C., & Duncanson, L. (2026). Oil spills and invasive species drive losses in Nigeria's mangrove forests. Philosophical Transactions of the Royal Society B, Article 20240480. https://doi.org/10.1098/rstb.2024.0480 Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninen, M. (2011).

Mangroves among the most carbon-rich forests in the tropics. Nature Geoscience, 4, 293, 297.

https://doi.org/10.1038/ngeo1123 Howard, J., Hoyt, S., Isensee, K., Pidgeon, E., & Telszewski, M. (Eds.). (2014). Coastal blue carbon:

Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows. Conservation International, IOC-UNESCO, IUCN.

Intergovernmental Panel on Climate Change. (2014). 2013 supplement to the 2006 IPCC guidelines for national greenhouse gas inventories: Wetlands. IPCC.

Kauffman, J. B., & Donato, D. C. (2012). Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests (Working Paper 86). Center for International Forestry Research.

Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., Lovelock, C. E., Schlesinger, W. H., & Silliman, B. R. (2011). A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. Frontiers in Ecology and the Environment, 9(10), 552, 560. https://doi.org/10.1890/110004 Nwankwo, C., et al. (2023). Carbon storage of mangrove sediments in Kibani, eastern Niger Delta, Nigeria:

Implications on the environment. Journal of Ecology and Natural Resources, 7(1), 000325.

https://doi.org/10.23880/jenr-16000325 Oguns, O. J., Olufemi, A., Henri-Ukoha, A., Grant, K. I., & Giadom, V. L. (2025). Spatial variation in carbon storage in mangrove ecosystems of the Niger Delta: Insights from the Bodo mangrove forest in Rivers State, Nigeria. Journal of Applied Sciences and Environmental Management, 29(10).

https://doi.org/10.4314/jasem.v29i10.36 United Nations Environment Programme. (2011). Environmental assessment of Ogoniland. UNEP.