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Research article

WETLAND MODIFICATION, MANGROVE BIODIVERSITY AND RURAL ECOTOURISM RESILIENCE IN THE CROSS RIVER ESTUARY, NIGERIA: GEOSPATIAL EVIDENCE FOR SUSTAINABLE ENVIRONMENTAL MANAGEMENT

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ABSTRACT

This study examines how wetland modification in the Cross River Estuary, Nigeria, affects mangrove biodiversity, mollusc resources, rural livelihoods and ecotourism-oriented environmental management. A geospatial and ecological survey design was used, combining land-use/land-cover change analysis, floristic quadrat records, mollusc distribution data, field observations and analysis of modification zones. Built-up land increased from 55.81 km² to 95.05 km² between 2003 and 2025, while mangrove cover declined from 172.69 km² to 135.40 km². Nypa palm increased from 98.70 km² to 121.13 km², indicating replacement pressure on native mangrove communities. Tree composition decreased from 64.00 individuals in relatively unmodified zones to 24.00 in highly modified zones, whereas shrub composition increased from 3.00 to 46.00. Mollusc abundance declined sharply with rising modification intensity. The results show that unregulated extraction, settlement expansion and invasive species growth weaken ecological integrity and rural livelihood security. The study integrates geospatial evidence, biodiversity assessment and ecotourism planning to support conservation-led wetland governance.

KEYWORDS

Wetland modification; Mangrove biodiversity; Environmental management; Rural ecotourism; Nypa palm; Cross River Estuary; Land-use/land-cover change; Nigeria

Introduction

Wetlands are strategic ecological interfaces between terrestrial and aquatic systems. They regulate floods, store carbon, recharge groundwater, support fisheries, filter pollutants and provide habitats for plant and animal communities. In estuarine environments, these functions are intensified because mangroves and freshwater swamp systems connect riverine, coastal and marine processes. The global importance of wetlands has been reinforced by recent assessments showing that wetland loss continues to undermine biodiversity, climate resilience, water security and the welfare of communities that depend on natural resources (Convention on Wetlands, 2021, 2025; FAO, 2023; IPBES, 2019). The Cross River Estuary is one of the most important wetland landscapes in south-eastern Nigeria. It includes mangrove swamp, freshwater swamp, mixed vegetation, water bodies, settlement edges, fishing camps and riverine communities. The estuary supports native mangrove species such as Rhizophora racemosa and Avicennia africana, as well as Nypa fruticans, Raphia hookeri, molluscs and other aquatic resources. These resources have ecological value, but they also function as livelihood assets used for fishing, fuelwood, construction, craft production, local trade and household subsistence. Their scenic and educational value also provides a foundation for conservation interpretation, rural ecotourism and environmental education around Calabar and neighbouring riverine settlements.

The difficulty, however, is that the same resources that sustain community livelihoods are being modified by settlement growth, sand filling, dredging, waste disposal, fuelwood extraction, fishing-related activities, open access use and the expansion of Nypa palm. In ecological terms, wetland modification refers to the physical alteration, degradation or replacement of wetland habitat through processes that disturb hydrology, vegetation structure, species distribution and ecosystem functioning. In rural livelihood terms, modification is paradoxical because households rely on wetland extraction for survival, yet excessive extraction reduces the very ecological capital that supports food security, income and future ecotourism opportunities. This study examines wetland modification as both a biodiversity conservation problem and a tourism-development problem. The study is situated in environmental management and rural ecotourism because wetland degradation cannot be understood only as land-cover change; it also affects livelihoods, destination interpretation, community learning and the possibility of conservation-funded tourism. Recent tourism scholarship has shown that nature-based and soft adventure tourism can support environmental stewardship when activities are planned around conservation, education and community participation (Nkambule & Venter, 2026). Similarly, ecotourism entrepreneurship requires an enabling local ecosystem that addresses regulation, access, safety, market linkages and resource constraints (Nkogho-Beyeme et al., 2026).

The problem addressed in this study is the limited integration of geospatial change evidence, field biodiversity data and rural ecotourism interpretation in the management of the Cross River Estuary. The original field records show changes in land cover, vegetation composition and mollusc abundance, but these changes require a stronger environmental-management explanation for international readership. The study therefore reframes the estuary as a social-ecological tourism landscape in which biodiversity conservation, livelihood resilience and responsible visitor development must be planned together. The aim of the study is to assess how wetland modification influences biodiversity conservation and rural ecotourism livelihood potential in the Cross River Estuary. Specifically, the study examines the pattern of estuarine resource exploitation; determines the extent of land-use/land-cover change and its drivers; assesses how modification influences flora and mollusc composition; and proposes conservation-oriented management options for wetland health, rural livelihood security and ecotourism education. Three hypotheses are tested: that no significant shift exists in land cover over time; that flora distribution and diversity do not vary significantly across modification zones; and that mollusc distribution does not vary significantly across the estuary's modification zones. The study contributes to environmental management and tourism-development literature in three ways. First, it provides empirical evidence of wetland transformation in a Nigerian estuary where mangrove biodiversity and livelihood use are closely connected. Second, it links biodiversity change to ecotourism planning, arguing that degraded wetlands lose scenic, educational and interpretive value. Third, it offers a rural-studies perspective by showing that conservation policy must address household dependence on wetland resources rather than treating communities only as drivers of degradation.

Literature review

Wetlands, mangroves and biodiversity conservation

Wetlands provide ecological, economic and socio-cultural services that are central to conservation and sustainable development. The Convention on Wetlands defines wise use as the maintenance of ecological character within the context of sustainable development. This is important because conservation should not be separated from the livelihood realities of communities that live around wetlands. Instead, management should balance resource use, biodiversity protection, restoration, environmental education and equitable benefit sharing (Convention on Wetlands, 2018, 2021, 2025). Mangrove wetlands are especially important because they function as transition zones between land and sea. They protect shorelines, provide nursery habitats for fish and crustaceans, stabilise sediments and support rich biological communities. Global mapping initiatives have improved understanding of mangrove extent and change, showing that remote sensing is indispensable for monitoring these ecosystems (Bunting et al., 2018, 2022). Mangroves are also geomorphically diverse; estuarine, deltaic, lagoonal and open-coast mangroves differ in structure, vulnerability and restoration potential (Worthington et al., 2020). Human-driven mangrove loss remains a major conservation concern. Although global mangrove loss has slowed in some regions, localised losses continue where coastal development, aquaculture, urban expansion and resource extraction are intense (Goldberg et al., 2020). In the Niger Delta, mangroves provide fish, shellfish, fuel, medicinal products and coastal protection, but they are also exposed to overexploitation, oil-related pressures, settlement expansion and weak conservation frameworks (Onyena & Sam, 2020). This wider Nigerian context makes the Cross River Estuary a critical case for analysing the link between wetland change and local livelihood security. The Cross River Estuary reflects a social-ecological relationship in which households, fishers, fuelwood traders, builders, craft users and tourism actors interact with the wetland. Native mangrove species, freshwater swamp vegetation and aquatic fauna are not isolated ecological units; they are embedded in everyday livelihood systems. When resource use is unregulated, mature mangrove structure can be replaced by disturbed mosaics of shrub communities and invasive vegetation. This process has direct implications for biodiversity conservation and ecotourism because a degraded wetland has reduced habitat complexity, reduced scenic quality and lower environmental-education value.

Wetland modification, land-cover change and rural livelihoods

Land-use/land-cover change is one of the main pathways through which human activity affects wetland biodiversity. Remote sensing studies show that wetland conversion, urban development, agriculture, aquaculture and tourism infrastructure can alter hydrological flows, reduce natural vegetation, fragment habitats and reduce ecosystem-service value (Judah & Hu, 2019; Meng & Dong, 2019). In the Cross River Estuary, this pressure is expressed through built-up expansion, sand filling, bare land creation, waste disposal and the replacement of native mangrove vegetation by Nypa palm belts. Rural wetland use is shaped by accessibility. Settlement edges, river channels, creeks and fishing camps create routes through which people reach resources. Areas close to Calabar South, Calabar Municipality and other accessible settlements are likely to experience more intense extraction than interior wetland sections. This follows the spatial principle that interaction is strongest where locations are near, accessible and economically connected. As nearby resources decline, exploitation often expands farther into the wetland, increasing pressure on previously less disturbed areas. For rural studies, the implication is that conservation cannot be achieved through restriction alone. Households extract mangrove poles, fish, molluscs, craft materials and fuelwood because these resources support subsistence and income. A viable wetland conservation strategy should therefore include alternative livelihood pathways, community-based monitoring, visitor interpretation, regulated harvesting, restoration incentives and benefit-sharing around nature-based tourism. Community approaches to mangrove ecotourism have shown that conservation can be strengthened when local residents are involved in management and derive value from the resource base (Henri & Ardiawati, 2020). The local tourism literature from Cross River and Akwa Ibom States further demonstrates that tourism development depends on the spatial organisation of services, attractions and visitor flows. Studies on hotel distribution, petrol filling stations, eateries, tourism support services and visitor numbers show that tourism and related urban services are spatially concentrated and influenced by access, infrastructure and market demand (Eneyo et al., 2017; Eneyo & Ekpenyong, 2018a, 2018b; Eneyo et al., 2022; Eneyo & Itu, 2024). These studies support the need to analyse wetland resources not only as ecological assets but also as part of the wider spatial economy of tourism and environmental management.

Ecotourism, environmental education and community-based destination value

Ecotourism depends on the conservation of natural and cultural resources. A wetland destination can support canoe experiences, birdwatching, mangrove boardwalks, environmental interpretation, school excursions, community guiding and scientific tourism. However, these activities require ecological integrity, visitor safety, community participation and low-impact infrastructure. The philosophical and educational foundations of tourism emphasise that tourism should create learning, cross-cultural respect and responsible engagement with place rather than only commercial consumption (Eneyo & Eneyo, 2025; Eneyo, 2025a, 2025e, 2025f). Cross River State has a strong cultural and nature-based tourism identity. Research on slave history theatre, Calabar Carnival, the Iboku Boat Regatta and sustainable livelihoods around Cross River

National Park shows that tourism resources can be interpreted as heritage, livelihood and community-development assets (Eneyo & Ekong, 2019; Eneyo & Essien, 2023; Eneyo et al., 2022b; Eneyo, 2025c, 2025d). These studies provide a regional foundation for treating the Cross River Estuary as a potential environmental-education and ecotourism landscape, especially if conservation values are integrated with rural livelihoods.

Tourism development also creates environmental responsibilities. Studies on plastic waste generated by eateries and the economic effects of curfew on nightlife in Calabar show that tourism-related activities can produce waste, safety concerns and livelihood shocks when governance is weak (Eneyo et al., 2018; Eneyo et al., 2021). In hospitality and tourism, staff wellbeing, training, fair work systems and organisational support influence service quality and visitor experience (Adam et al., 2026; Mafini & Slabbert, 2026). These issues are relevant to wetland ecotourism because community guides, canoe operators and conservation educators require training, fair benefit sharing and occupational safety. The contribution of higher education to tourism and hospitality development is equally important. Environmental education can help communities, students and visitors understand wetland functions, biodiversity values and the consequences of modification (Eneyo, 2025b, 2025e). In the Cross River Estuary, a university-supported wetland interpretation programme could connect GIS evidence, field ecology, rural livelihoods and responsible tourism. Such a programme would transform the wetland from an exploited open-access resource into a living classroom for biodiversity conservation and sustainable destination management.

Theoretical framework

The study is conceptually anchored on the Driver-Pressure-State-Impact-Response framework and the Intermediate Disturbance Hypothesis. The Driver-Pressure-State-Impact-Response framework explains how broad drivers such as population growth, livelihood needs, urban expansion, weak regulation and market demand produce pressures such as fuelwood extraction, sand filling, dredging, settlement encroachment and waste disposal. These pressures alter the state of the wetland by changing land cover, vegetation composition and mollusc abundance. The impacts are biodiversity loss, altered habitat structure, reduced ecological health and weakened livelihood security. Responses include land-use planning, community education, conservation policy, ecological restoration and alternative livelihood development. The Intermediate Disturbance Hypothesis helps to interpret species variation along modification gradients. Relatively unmodified zones may preserve mature native vegetation, modified zones may show transitional structure, while highly modified zones may favour disturbance-tolerant shrubs and invasive or opportunistic species. In the Cross River Estuary, this framework is useful because the data show declining tree composition and increasing shrub dominance with rising modification. Such ecological shifts are important for ecotourism planning because visitor experience and conservation education depend on the integrity, diversity and interpretability of the wetland landscape. Together, the two frameworks support an integrated interpretation of the evidence. The Driver-Pressure-State-Impact-Response framework explains why modification occurs and what institutional responses are required, while the Intermediate Disturbance Hypothesis explains how ecological communities change along the modification gradient. This combined framework is appropriate for Q1-level environmental tourism analysis because it connects land-cover change, biodiversity response, livelihoods and management action rather than presenting the statistics as isolated outputs.

Methodology

The study adopted an ecological field survey and geospatial change-detection design. The study area was the inner part of the Cross River Estuary bounded by the Cross River, Calabar River and Great Kwa River channels. The estuary lies within a humid tropical environment in south-eastern Nigeria and includes mangrove swamp, freshwater swamp, mixed vegetation, water bodies, rural fishing camps, islands and urbanising settlements. The climate is characterised by high rainfall, high relative humidity, brackish water conditions and low-lying hydromorphic soils. Data were obtained from field observation, quadrat sampling, mollusc records, land-use/land-cover interpretation and review of the original GIS and ecological field outputs. Land-use/land-cover classes included built-up area, mangrove, Nypa palm, freshwater swamp, farmland, mixed vegetation, open or bare land, waste dump and water body. Area values were reported in square kilometres and all variables were rounded to two decimal places. The land-use/land-cover component compared the 2003 and 2025 classification outputs. Change was computed by subtracting 2003 area from 2025 area. Percentage change was calculated relative to the 2003 value, while annual change was derived by dividing the total change by the 22-year period. These calculations enabled the study to identify both the direction and magnitude of estuarine transformation. A publication-quality figure was prepared to visualise the direction of change across land-cover classes.

The ecological field component was organised around three modification zones: relatively unmodified, modified and highly modified. These zones represented increasing levels of human disturbance, resource extraction and vegetation change. Floristic variables included tree composition, shrub composition, tree diversity, shrub diversity, tree Importance Value Index and shrub Importance Value Index. Mollusc and extraction variables included mangrove stump counts, expected mangrove quantity, Tympanotonus fuscatus abundance and Littorina species abundance. Descriptive statistics were used to summarise land-cover change, vegetation composition and mollusc distribution. One-way analysis of variance was used to test land-cover and floristic variation, while two-way analysis of variance was used for mollusc distribution across modification zones and mollusc groups. The statistical decisions were interpreted professionally by aligning each test statistic with the relevant hypothesis and ecological meaning. The analysis emphasised the practical importance of the results for conservation and ecotourism, not only statistical significance. Ethical consideration was addressed by using aggregate ecological, spatial and field records. No personally identifiable respondent information was reported. The data were used solely for academic analysis and environmental management interpretation. The figures and tables were also accompanied by coherent explanatory text so that each result is linked to the study objectives, hypotheses and implications for wetland conservation.

Results and discussion

Pattern of estuarine resource exploitation

Resource exploitation in the Cross River Estuary followed two dominant spatial patterns. First, extraction moved from built-up edges into vegetated sections of the wetland. Second, extraction followed rivers and creeks, making channels important access corridors. Areas close to Calabar and other settlements showed greater disturbance than interior zones. This pattern indicates that accessibility, market demand and open access are major drivers of ecological modification. The most frequently exploited resources were mangroves and other woody species used for fuelwood, fish smoking, construction poles, scaffolding, craft materials and local trade. Rhizophora racemosa and Avicennia africana had high use values because they serve multiple livelihood purposes. Oxystigma mannii, Uapaca guineensis, Elaeis guineensis, Raphia hookeri and Laguncularia racemosa were also important. By contrast, Nypa fruticans and several shrubs had lower direct use values and therefore tended to increase in disturbed locations where heavily used native trees had declined. This exploitation pattern has strong conservation and ecotourism implications. The same wetland resources that support local livelihoods also provide scenic, educational and ecological value for nature-based tourism. When high-value native mangroves are removed and replaced by lower-use or invasive species, the wetland loses habitat complexity and interpretive richness. Community-based ecotourism can therefore become part of a conservation response only when it is linked to regulated extraction, restoration of native mangroves and local livelihood incentives.

Study area context and spatial logic of modification

Figure 1 presents the study area context of the Cross River Estuary and the spatial logic of modification. The estuary is represented as a connected wetland system influenced by the Cross River, Calabar River and Great Kwa River corridors. The figure shows the relationship between the urban edge, mangrove and freshwater swamp areas, Nypa pressure zones and resource-use corridors. It is important because it clarifies why modification is spatially uneven: disturbance is strongest where settlement access, river routes and market demand intersect.

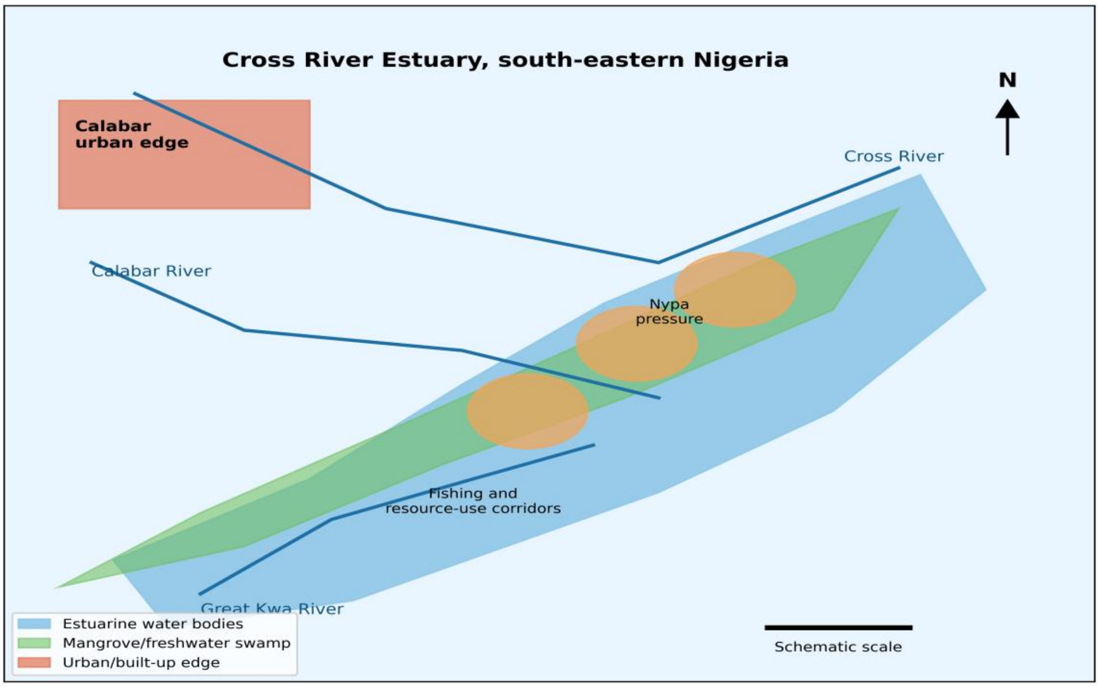

Figure 1. Study area context of the Cross River Estuary, Nigeria.
Source: Author's GIS-based study-area description (2026).

Land-use/land-cover change in the estuary

Table 1 summarises the calculated land-use/land-cover change between 2003 and 2025. The table is central to the study because it identifies the direction, magnitude and annual rate of change for each land-cover class. The most important changes were the expansion of built-up land and Nypa palm, and the decline of mangrove, freshwater swamp and mixed vegetation. These figures confirm that the estuary experienced both direct conversion and ecological replacement. Figure 2 complements Table 1 by visualising the magnitude and direction of change. Positive values represent land-cover expansion, while negative values represent contraction. The figure makes the core transformation immediately visible: built-up area and Nypa palm increased strongly, whereas mangrove cover declined sharply. The figure therefore supports the interpretation that human settlement pressure and invasive or opportunistic vegetation expansion are the two most important spatial changes in the estuary.

Built-up area increased from 55.81 km² in 2003 to 95.05 km² in 2025, representing an increase of 39.24 km² or 70.31%. The annual increase was 1.78 km², equivalent to about 3.20% per year over the 22-year interval. This confirms that urban expansion and settlement-related land demand were the strongest direct drivers of wetland conversion. The increase in built-up land is environmentally significant because it is likely to be associated with sand filling, construction, waste generation, access-road creation and pressure on hydrological flows. Mangrove cover declined from 172.69 km² to 135.40 km², a loss of 37.29 km² or 21.59%. The annual rate of decline was 1.69 km². Freshwater swamp declined by 12.08 km², while mixed vegetation declined by 9.48 km². These losses indicate that natural wetland vegetation was reduced by both physical development and resource exploitation. Nypa palm increased from 98.70 km² to 121.13 km², a gain of 22.43 km² or 22.73%, suggesting that disturbed native mangrove zones were increasingly colonised by Nypa palm. The land-cover ANOVA indicated a statistically significant shift in land-cover classes over time, $F = 87.23$, $p < 0.01$. The null hypothesis of no significant land-cover shift is therefore rejected. Scheffe comparisons indicated that built-up area, Nypa palm and mangrove were the principal contributors to the observed variation. From a conservation perspective, these classes represent the most important management targets because they describe the central transformation of the estuary: urban expansion and Nypa increase on one side, native mangrove decline on the other.

Table 1. Land-use/land-cover change in the Cross River Estuary, 2003-2025.

Land-cover class	2003 (km²)	2025 (km²)	Change (km²)	Change (%)	Annual change (km²/yr)	Annual change (%/yr)	Trend
Built-up area	55.81	95.05	39.24	70.31	1.78	3.20	Increase
Mangrove	172.69	135.40	-37.29	-21.59	-1.69	-0.98	Decrease
Nypa palm	98.70	121.13	22.43	22.73	1.02	1.03	Increase
Freshwater swamp	55.58	43.50	-12.08	-21.73	-0.55	-0.99	Decrease
Farmland	8.23	4.83	-3.40	-41.31	-0.15	-1.88	Decrease
Mixed vegetation	38.63	29.15	-9.48	-24.54	-0.43	-1.12	Decrease
Open/bare land	1.27	1.85	0.58	45.67	0.03	2.08	Increase
Waste dump	0.12	0.08	-0.04	-33.33	0.00	-1.52	Decrease
Water body	192.15	192.19	0.04	0.02	0.00	0.00	Increase

Source: Author's fieldwork and GIS analysis (2026).

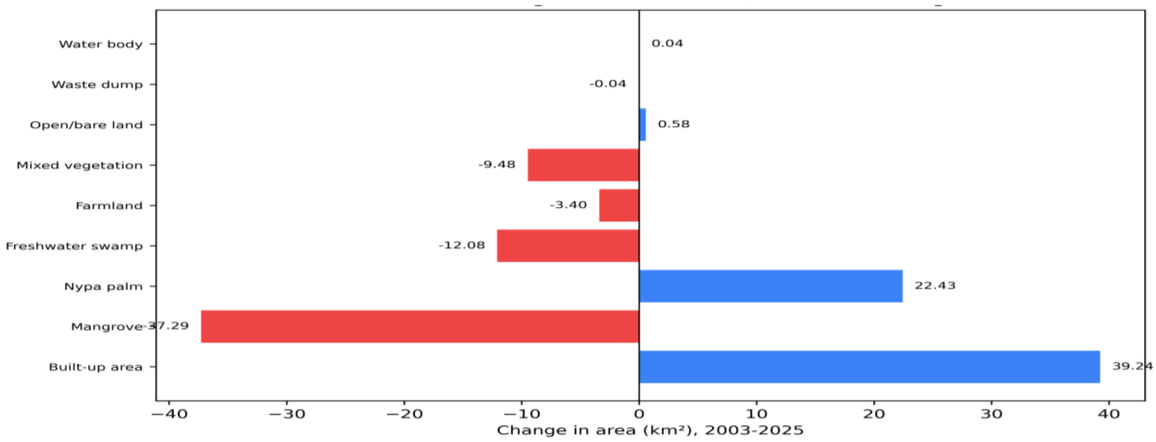

Figure 2. Direction and magnitude of land-use/land-cover change between 2003 and 2025.

Source: Author's analysis (2026).

Floristic composition and diversity across modification zones

Floristic data show a clear shift in vegetation structure along the modification gradient. Relatively unmodified areas were dominated by native tree species, while highly modified areas had greater shrub composition. Table 2 presents the two-decimal summary of species composition, diversity and importance values. The table is important because it shows not merely that vegetation changed, but that the ecological structure shifted from mature tree dominance towards shrub and disturbance-tolerant dominance. Figure 3 visually explains the contrast between tree and shrub composition across the modification zones. In relatively unmodified areas, tree composition was far higher than shrub composition. In highly modified areas, the relationship reversed, with shrub composition exceeding tree composition. This figure is therefore a direct visual representation of ecological restructuring. It demonstrates that increasing modification does not simply reduce vegetation; it changes the type of vegetation that dominates the wetland. In relatively unmodified areas, tree composition was 64.00 individuals compared with 3.00 shrubs. Rhizophora racemosa was the dominant species, supported by Avicennia africana, Oxystigma mannii, Nypa fruticans and Carapa procera. The tree diversity index was 2.23 and tree Importance Value Index was 287.32, showing that native tree structure remained ecologically important in the least disturbed zone. This zone is therefore a conservation priority because it still retains the structural qualities associated with mature mangrove ecosystems.

In modified areas, tree composition declined to 40.00, while shrub composition increased to 8.00. Nypa fruticans became the most significant species, with a high importance value and numerical dominance. This confirms that partial disturbance favoured species that can colonise altered hydrological and opencanopy conditions. Native mangrove indicators such as Rhizophora racemosa and Avicennia africana were still present, but their ecological dominance had been reduced. In highly modified areas, tree composition declined further to 24.00, while shrub composition rose to 46.00. Shrub diversity increased to 1.38, while tree diversity declined to 1.02. This pattern confirms the ecological replacement of native tree-dominated wetland structure by disturbance-tolerant shrub communities. Although the highly modified zone may show visible vegetation cover, the composition is less desirable from a conservation and ecotourism perspective because mature mangrove integrity has been weakened. The flora ANOVA showed significant variation in species distribution and diversity across the modification gradient, $F = 5.14$, $p = 0.01$. The null hypothesis of no significant variation is rejected. The interpretation is that modification intensity significantly influences the distribution and diversity of flora species, with the strongest contrast between relatively unmodified and highly modified zones. This finding supports the Intermediate Disturbance logic: disturbance may increase the presence of some opportunistic species, but it reduces the structural dominance of native mangrove trees that sustain wetland ecological character.

Table 2. Species composition, diversity and Importance Value Index across modification zones.

Modification zone	Tree composition	Shrub composition	Tree diversity	Shrub diversity	Tree IVI	Shrub IVI
Relatively unmodified	64.00	3.00	2.23	0.15	287.32	16.63
Modified	40.00	8.00	1.25	0.40	257.47	42.44
Highly modified	24.00	46.00	1.02	1.38	162.12	137.84

Source: Author's fieldwork (2026).

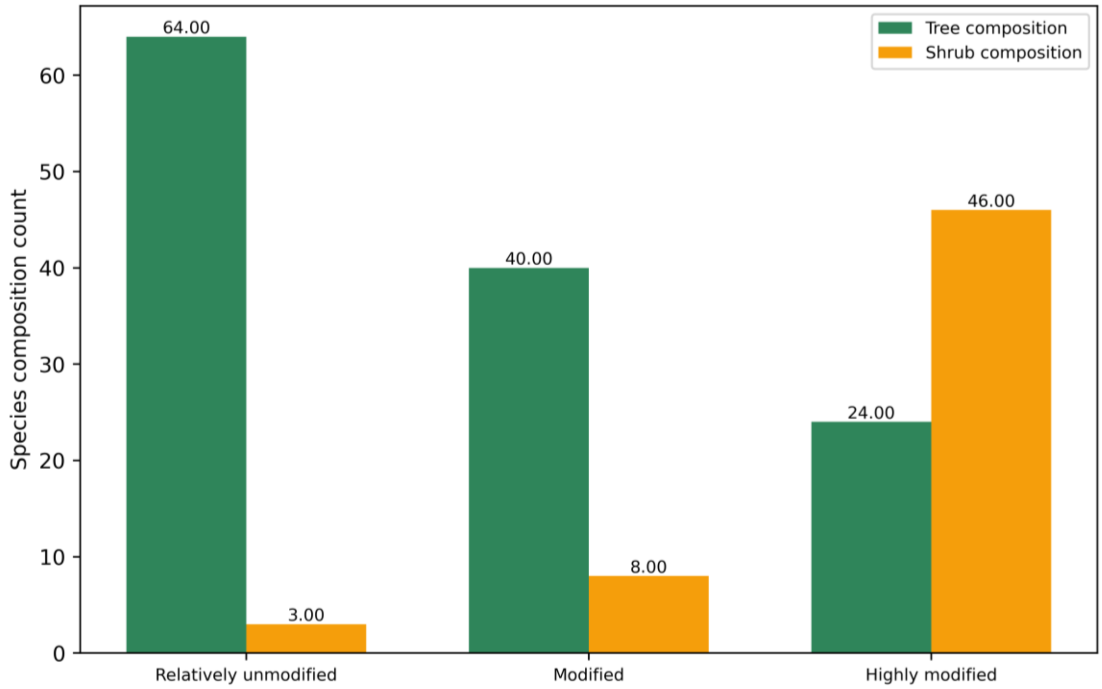

Figure 3. Tree and shrub composition across the wetland modification gradient.
Source: Author's fieldwork (2026).

Importance values and the ecological role of Nypa palm

Importance Value Index results confirm that species significance changed along the disturbance gradient. In relatively unmodified areas, Rhizophora racemosa had the highest IVI of 52.00, followed by Nypa fruticans with 38.94 and Oxystigma mannii with 28.82. This indicates that native mangrove structure remained ecologically strong in less disturbed zones, even though Nypa palm was already present. In modified areas, Nypa fruticans recorded an IVI of 154.22, far above other species. This result is ecologically important because it indicates that Nypa palm had become the dominant species in disturbed habitats. In highly modified areas, Nypa fruticans still recorded the highest IVI at 46.08, while Crystopogia senegalense followed with 33.22. The transition from Rhizophora dominance to Nypa and shrub dominance is a clear sign of modification-driven vegetation restructuring. For conservation and rural ecotourism, the Nypa palm trend is a management concern. Nypa may provide some local uses, but its expansion can reduce native mangrove habitat quality and alter the ecological identity of the estuary. Effective management should therefore prioritise native mangrove restoration, community harvesting rules and monitoring of Nypa expansion in disturbed channels and settlement-edge areas.

Mollusc distribution and mangrove extraction pressure

Mollusc distribution declined sharply with increasing modification. Table 3 shows the relationship between mangrove stump counts, expected mangrove extraction quantity and mollusc abundance across the three zones. The table is essential because it connects vegetation disturbance to faunal decline and livelihood implications. As mangrove stump counts and expected extraction quantities increased, mollusc abundance declined, indicating a likely relationship between habitat disturbance and resource depletion. Figure 4 provides a visual explanation of the mollusc trend. Both Tympanotonus fuscatus and Littorina species were most abundant in the relatively unmodified zone and declined sharply in the modified and highly modified zones. The figure shows that the decline is not limited to one species group; it reflects a broader zonal effect associated with habitat modification. This visual pattern supports the statistical result that modification zone is the major factor explaining mollusc distribution. The relatively unmodified zone had only 2.00 mangrove stumps and recorded 19.47 kg of Tympanotonus fuscatus and 12.23 kg of Littorina species. In the modified zone, mangrove stumps increased to 8.00, while Tympanotonus fuscatus declined to 2.08 kg and Littorina species declined to 0.85 kg. In the highly modified zone, mangrove stumps increased to 12.00, while Tympanotonus fuscatus dropped to 0.40 kg and Littorina species dropped to 0.11 kg.

The two-way ANOVA showed that mollusc distribution varied significantly by modification zone, $F = 22.51$, $p < 0.01$. The difference between mollusc groups was not statistically significant, $F = 2.14$, $p > 0.05$, and the zone-by-group interaction was not significant, $F = 1.36$, $p = 0.32$. The professional interpretation is that the modification gradient, rather than mollusc group identity, explains the major variation in mollusc distribution. The null hypothesis of no significant variation across zones is rejected. This result strengthens the ecological argument that mangrove modification has cascading effects on associated fauna. Molluscs depend on wetland habitat conditions, substrate stability and organic matter linked to mangrove structure. Where mangrove cutting and physical disturbance increase, mollusc abundance falls. From a rural livelihood perspective, this decline affects food, trade and household income. From an ecotourism perspective, declining mollusc and mangrove integrity weakens the interpretive value of the wetland as a living biodiversity classroom.

Table 3. Mollusc distribution and mangrove extraction indicators across modification zones.

Modification zone	Mangrove stumps	Expected mangrove quantity (kg)	Tympanotonus fuscatus (kg)	Littorina species (kg)
Relatively unmodified	2.00	209.00	19.47	12.23
Modified	8.00	2700.00	2.08	0.85
Highly modified	12.00	3540.00	0.40	0.11

Source: Author's fieldwork (2026).

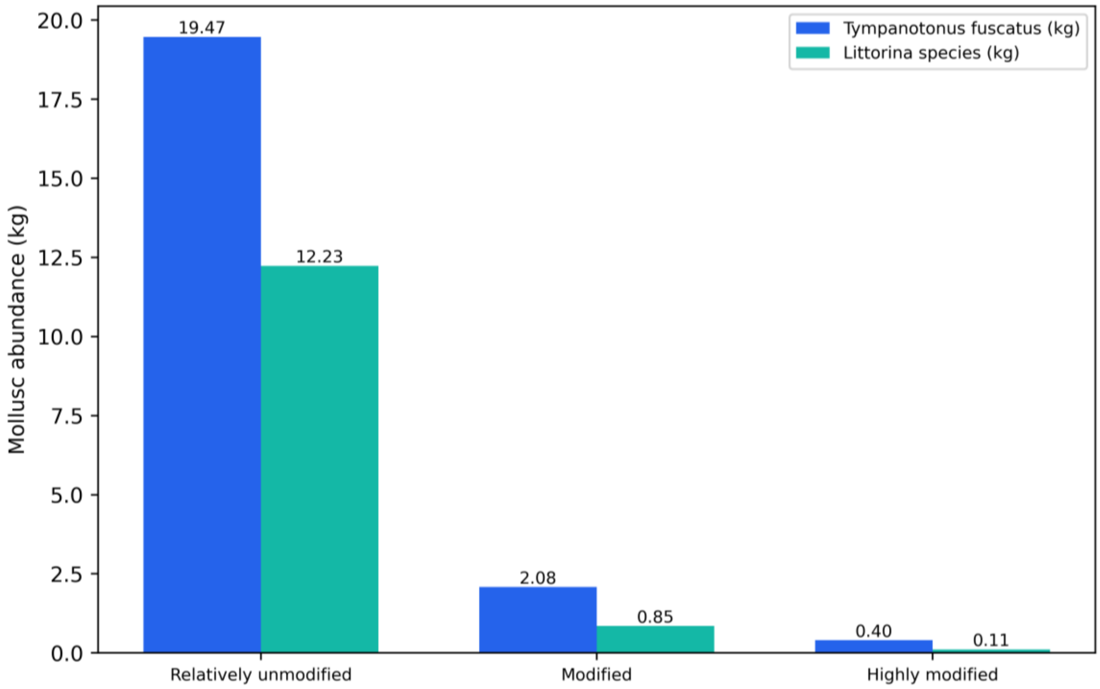

Figure 4. Mollusc distribution across the wetland modification gradient.
Source: Author's fieldwork (2026).

Statistical decisions and hypothesis interpretation

Table 4 consolidates the statistical decisions for the study hypotheses. The table is included to improve methodological clarity and prevent the common error of reporting test statistics without clearly linking them to decisions and interpretations. All three hypotheses were rejected either fully or for the relevant zonal effect, indicating that modification significantly affects land cover, flora distribution and mollusc abundance. The statistical pattern is coherent across the tables and figures. Table 1 and Figure 2 show land-cover transformation; Table 2 and Figure 3 show vegetation restructuring; Table 3 and Figure 4 show faunal decline along the modification gradient. Table 4 then integrates these empirical results into hypothesis-level decisions. The consistency across land-cover, flora and mollusc indicators strengthens the conclusion that wetland modification is not isolated but systemic.

Table 4. statistical decisions for the study hypotheses.

Hypothesis tested	Test statistic	decision	Interpretation
No significant shift exists in land cover over time.	$F = 87.23$, $p < 0.01$	Rejected	Land-cover classes shifted significantly between 2003 and 2025, especially built-up area, mangrove and Nypa palm.
No significant variation exists in flora distribution and diversity across zones.	$F = 5.14$, $p = 0.01$	Rejected	Flora composition and diversity varied significantly along the modification gradient.
Mollusc distribution does not vary significantly across zones.	Fzone = 22.51, $p < 0.01$; Fgroup = 2.14, $p > 0.05$; Finteraction = 1.36, $p = 0.32$	Rejected for zones only	Mollusc abundance differed significantly by modification zone, while group and interaction effects were not significant.

Source: Statistical outputs (2026).

Implications for ecotourism, conservation and rural studies

The findings have direct implications for ecotourism planning. The Cross River Estuary has ecological features that can support wetland interpretation, conservation education, birdwatching, mangrove trails, community canoe experiences and rural heritage interpretation. However, these opportunities depend on the conservation of native mangrove habitats and associated aquatic biodiversity. Uncontrolled settlement expansion, fuelwood extraction and Nypa palm colonisation can reduce the ecological quality required for sustainable ecotourism development. For rural livelihoods, the findings show that wetland degradation is not only an environmental problem. It is also a livelihood-security problem because the decline of mangrove and mollusc resources affects food, income, fuelwood access and small-scale trade. Conservation programmes must therefore include alternative livelihood options. Potential options include eco-guiding, restoration work, craft interpretation, regulated mollusc harvesting, community nurseries for native mangroves, canoe-based interpretation and local conservation education.

For environmental management, the most urgent priorities are land-use zoning, protection of relatively unmodified interior zones, native mangrove restoration and control of encroachment around settlement edges. Areas where mangrove has been converted to built-up land or colonised by Nypa should be mapped as restoration and management priority zones. Environmental impact assessment should be mandatory for dredging, sand filling, construction and tourism infrastructure within the estuary. The results also show that ecotourism should not be treated as an automatic solution. Poorly managed tourism can create waste, access pressure, safety concerns and habitat disturbance. Therefore, any ecotourism development in the estuary should be low-impact, community-led and conservation-funded. Visitor infrastructure should be restricted to suitable zones and should include boardwalks, interpretive signage, waste controls, carrying-capacity guidance and revenue-sharing mechanisms for local conservation. A university-community-government partnership would be particularly useful. The University of Calabar and relevant environmental agencies can support monitoring, wetland education and student field training. Community associations can support local enforcement and guiding, while tourism operators can help design responsible visitor experiences. Such a partnership would align conservation science with rural livelihood needs and would strengthen the estuary as a site for environmental education and sustainable destination development.

Conclusion and recommendations

This study demonstrates that wetland modification in the Cross River Estuary has altered land cover, vegetation composition and mollusc distribution. Between 2003 and 2025, built-up area increased by 39.24 km² and Nypa palm increased by 22.43 km², while mangrove declined by 37.29 km². These changes show that the estuary is undergoing a transition from native wetland vegetation towards urbanised and disturbance-tolerant cover types. The floristic evidence shows that native tree composition declines with increasing modification, while shrub composition increases. Relatively unmodified zones retain stronger native mangrove structure, while highly modified zones are characterised by shrub dominance and reduced mature tree integrity. Mollusc abundance also falls sharply with increasing modification, confirming that habitat disturbance affects associated fauna and local livelihood resources. The study recommends effective land-use planning and wetland zoning to regulate development in sensitive mangrove and freshwater swamp areas. Native mangrove restoration should be prioritised in degraded zones, and Nypa palm expansion should be monitored and controlled where it replaces native species. Community-based conservation should be strengthened through alternative livelihoods, environmental education and benefit-sharing.

Local residents should be supported to participate in eco-guiding, restoration, craft production, controlled harvest systems and wetland monitoring. Government agencies, universities, conservation organisations and tourism stakeholders should collaborate to create a Cross River Estuary wetland conservation and ecotourism education programme. Such an approach can protect biodiversity while supporting rural livelihoods and responsible nature-based tourism. The study's key contribution is the integration of geospatial evidence, biodiversity data and ecotourism livelihood interpretation. It shows that wetland management in the Cross River Estuary should move beyond isolated conservation enforcement towards a coordinated model that links restoration, rural livelihoods, environmental education and low-impact tourism development.

Declarations

Ethics approval: The manuscript confirms institutional ethics requirements, data ownership and permission to reuse the dataset.

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Data availability: GIS files and field sheets are available from the authors on reasonable request.

Authors contribution: The authors conceptualised the study, analysed the data, interpreted the findings and prepared the manuscript.

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References

Adam, I., Bukari, S., & Amuquandoh, F. E. (2026). Hospitality on the edge: Effects of occupational stress on the psychological wellbeing of hotel employees in Ghana. African Journal of Hospitality, Tourism and Leisure, 15(1), 68-78. https://doi.org/10.46222/ajhtl.19770720.718

Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R. M., Thomas, N., Tadono, T., Worthington, T. A., Spalding, M., Murray, N. J., & Rebelo, L.-M. (2022). Global mangrove extent change 1996-2020: Global Mangrove Watch Version 3.0. Remote Sensing, 14(15), 3657. https://doi.org/10.3390/rs14153657

Bunting, P., Rosenqvist, A., Lucas, R. M., Rebelo, L.-M., Hilarides, L., Thomas, N., Hardy, A., Itoh, T., Shimada, M., & Finlayson, C. M. (2018). The Global Mangrove Watch - A new 2010 global baseline of mangrove extent. Remote Sensing, 10(10), 1669. https://doi.org/10.3390/rs10101669

Convention on Wetlands. (2018). Global Wetland Outlook: State of the world's wetlands and their services to people. Secretariat of the Convention on Wetlands. https://doi.org/10.69556/GWO-2018-eng

Convention on Wetlands. (2021). Global Wetland Outlook: Special edition 2021. Secretariat of the Convention on Wetlands. https://doi.org/10.69556/GWO-2021-eng

Convention on Wetlands. (2025). Global Wetland Outlook 2025: Valuing, conserving, restoring and financing wetlands. Secretariat of the Convention on Wetlands. https://doi.org/10.69556/GWO-2025-eng

Eneyo, V. B. (2025a). Essentials of tourism for beginners (pp. 1-91). University of Calabar Press.

Eneyo, V. B. (2025b). Ethics and social responsibility in hospitality and tourism education. In Tourism and the environment (Vol. 1, pp. 358-374). University of Calabar Press.

Eneyo, V. B. (2025c). Exploring sustainable livelihoods and socio-economic constraints in the Cross River National Park, Oban Division, Nigeria. Journal of Environmental and Tourism Education, 8(1), 569-587.

Eneyo, V. B. (2025d). Leveraging Efik cultural festivals as strategic tools for tourism development and poverty reduction in Calabar, Nigeria. Journal of Environmental and Tourism Education, 8(1), 530-547.

Eneyo, V. B. (2025e). The role of higher education in tourism and hospitality development. In Tourism and the environment (Vol. 1, pp. 340-357). University of Calabar Press.

Eneyo, V. B. (2025f). Tourism for beginners II (pp. 1-117). University of Calabar Press.

Eneyo, V. B., & Ekong, M. O. (2019). Slave history theatre as center for tourists' pull in Cross River State, Nigeria. Journal of Tourism and Heritage Studies, 8(1), 100-123.

Eneyo, V. B., & Ekpenyong, E. J. (2018a). Spatial distribution of petrol filling stations in Calabar South Local Government Area, Cross River State. Multi-Disciplinary Journal of Research and Development Perspectives, 7(1), 66-83.

Eneyo, V. B., & Ekpenyong, E. J. (2018b). The contribution of tourism support services in the socio-economic development of Uyo Urban, Nigeria. Multi-Disciplinary Journal of Research and Development Perspectives, 7(2), 28-44.

Eneyo, V. B., & Eneyo, M. B. (2025). Philosophy of tourism: A philosophical approach to tourism studies. University of Calabar Press.

Eneyo, V. B., & Essien, D. A. (2023). Economic and social impacts of cultural festivals: A comprehensive analysis of Calabar Carnival, Nigeria. Nigerian Journal of Social and Development Issues, 11(1), 116-133.

Eneyo, V. B., & Itu, P. C. O. (2024). Variation in visitor numbers and contributing factors at tourism attractions in Akwa Ibom State, Nigeria. World Tourism Journal, 2(2), 83-98.

Eneyo, V. B., Ajake, A. O., & Ekpenyong, E. J. (2018). Assessing plastic wastes generation by eateries in Calabar, Nigeria. World Environment Journal, 2(1), 95-106.

Eneyo, V. B., Ajake, A. O., Offiong, E. E., Ushie, M. A., & Akpan, N. A. (2022a). Exploring spatial pattern of eateries in Calabar City, Cross River State, Nigeria. Spatial Information Research, 31(2), 167-179.

Eneyo, V. B., Attah, F. M., Ekong, M. O., Offiong, E. E., Ekpo, E. E., Antai, A. S., Obi, F. B., & Essien, D. A. (2022b). Marketing strategies of niche tourism products: A case study of Iboku Boat Regatta practised by the Efik people of South Eastern Nigeria. African Journal of Hospitality, Tourism and Leisure, 11, 541-554.

Eneyo, V. B., Bassey, B., & Ekpenyong, E. J. (2017). Mapping hotel distribution in Calabar, Cross River State, Nigeria. World Environment Journal, 1(1), 66-83.

Eneyo, V. B., Oba, D. O., Ochiche, C. A., Essien, D. A., & Antai, A. S. (2021). Economic impacts of curfew imposition on the nightclub industry in Calabar Metropolis, Nigeria. African Journal of Hospitality, Tourism and Leisure, 10(3), 955-971.

Food and Agriculture Organization of the United Nations. (2023). The world's mangroves 2000-2020. FAO.

Goldberg, L., Lagomasino, D., Thomas, N., & Fatoyinbo, T. (2020). Global declines in human-driven mangrove loss. Global Change Biology, 26(10), 5844-5855. https://doi.org/10.1111/gcb.15275

Henri, H., & Ardiawati, S. (2020). Ecotourism development of Munjang mangrove forest and conservation efforts based on community approach. BIOLINK: Jurnal Biologi Lingkungan Industri Kesehatan, 7(1), 106-116. https://doi.org/10.31289/biolink.v7i1.2952

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (2019). Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES Secretariat. https://doi.org/10.5281/zenodo.3831673

Judah, A., & Hu, B. (2019). The integration of multi-source remotely-sensed data in support of the classification of wetlands. Remote Sensing, 11(13), 1537. https://doi.org/10.3390/rs11131537

Mafini, M., & Slabbert, E. (2026). Money matters: Job satisfaction in the South African tourism and hospitality industry. African Journal of Hospitality, Tourism and Leisure, 15(1), 11-20. https://doi.org/10.46222/ajhtl.19770720.713

Meng, L., & Dong, J. (2019). LUCC and ecosystem service value assessment for wetlands: A case study in Nansi Lake, China. Water, 11(8), 1597. https://doi.org/10.3390/w11081597

Nkambule, N. M., & Venter, D. (2026). Hiking as soft adventure tourism in South Africa: Insights from a systematised literature review. African Journal of Hospitality, Tourism and Leisure, 15(1), 1-10. https://doi.org/10.46222/ajhtl.19770720.712

Nkogho-Beyeme, R., Thomas, P., & Schachtebeck, C. (2026). Exploring the tourism entrepreneurial ecosystem of Kruger National Park: Opportunities, challenges, and strategic solutions for small and medium-sized enterprises. African Journal of Hospitality, Tourism and Leisure, 15(1), 177-185. https://doi.org/10.46222/ajhtl.19770720.728

Onyena, A. P., & Sam, K. (2020). A review of the threat of oil exploitation to mangrove ecosystem: Insights from Niger Delta, Nigeria. Global Ecology and Conservation, 22, e00961. https://doi.org/10.1016/j.gecco.2020.e00961

Worthington, T. A., zu Ermgassen, P. S. E., Friess, D. A., Krauss, K. W., Lovelock, C. E., Thorley, J., Tingey, R., Woodroffe, C. D., Bunting, P., Cormier, N., Lagomasino, D., Lucas, R. M., Murray, N. J., Sutherland, W. J., & Spalding, M. (2020). A global biophysical typology of mangroves and its relevance for ecosystem structure and deforestation. Scientific Reports, 10, 14652. https://doi.org/10.1038/s41598-020-71194-5