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SPATIO-TEMPORAL PATTERNS OF FOREST LOSS AND GAIN IN OKOMU FOREST RESERVE, NIGERIA

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Background: Tropical forests in Sub-Saharan Africa face rapid and often irreversible transformation due to population growth, agricultural expansion, and illegal logging. Nigeria exhibits some of the highest deforestation rates globally, and protected areas such as the Okomu Forest Reserve (OFR) continue to experience severe anthropogenic pressure. Limited high-resolution, long-term data on forest loss and gain constrain conservation planning and enforcement, highlighting the need for robust spatiotemporal assessments of forest dynamics. **Objectives:** This study aims to quantify annual and cumulative forest loss and gain in OFR from 2000 to 2024 using the Hansen Global Forest Change dataset. It has been hypothesized that forest loss significantly exceeds gain, leading to fragmented regrowth and persistent net forest cover deficits, with implications for biodiversity, carbon storage, and ecosystem resilience. **Methods:** Forest dynamics in the OFR, south-western Nigeria was assessed from 2000 to 2024 using the Hansen Global Forest Change dataset (30 m resolution) within Google Earth Engine. Forest was defined as ≥30% canopy cover in 2000. Annual and cumulative forest loss and gain were calculated by overlaying the forest mask with the loss, gain, and lossyear layers. Net forest change was computed as gain minus loss. Spatial outputs were exported as GeoTIFFs and summarized in tabular form. While high-resolution, satellite-based data may underrepresent small-scale disturbances; this approach provides consistent, multi-decadal insights into forest cover trends in a protected tropical landscape. **Results:** In 2000, OFR contained 99,840 ha of forest. Between 2001 and 2024, 17,262 ha (17.3%) were lost, while only 4,100 ha (4.1%) regenerated, resulting in a net decline of 13,162 ha (13.2%). Forest loss was spatially concentrated along the eastern and north-eastern boundaries, with scattered interior clearings, reflecting ongoing agricultural expansion, logging, and human encroachment. Regrowth was fragmented and localized, primarily in peripheral or abandoned areas, insufficient to restore ecosystem function. These patterns indicate progressive fragmentation of interior forest, reduced habitat connectivity, diminished carbon storage, and heightened vulnerability of wildlife. Annual loss varied, with peaks in 2001, 2002, 2013, 2017, 2018, and 2024, highlighting persistent, rather than episodic, disturbances. **Conclusion:** This study confirms that OFR has undergone substantial forest degradation from 2000 to 2024, with net loss, limited regrowth, and fragmentation threatening biodiversity, carbon storage, and ecosystem stability. Notably, gaps remain in detecting fine-scale disturbances and understanding socio-economic drivers of forest change, highlighting unresolved challenges for comprehensive conservation planning and effective ecosystem management.

Keywords: Hansen Global Forest Change; remote sensing; forest degradation; carbon accumulation; biodiversity; climate risks; SDG 13; SDG 15.

INTRODUCTION

Tropical forests across Sub-Saharan Africa are undergoing rapid and often irreversible transformation, driven primarily by demographic expansion, agricultural intensification, illegal logging, and widespread infrastructure development (Rudel, 2013; Aleman et al., 2018; Lunku et al., 2024). Nigeria remains among the countries with the highest deforestation rates globally, and protected areas such as the Okomu Forest Reserve (OFR), Shasha Forest Reserve, Falgore Game Reserve, and Ngel Nyaki Forest Reserve, among others, continue to experience intense anthropogenic pressure and progressive degradation despite their formal conservation status (Olokeogun et al., 2014; Suleiman et al., 2017; Adeniji et al., 2023; Lukman et al., 2025; Akomolafe & Anumeh, 2025).

OFR is one of the remnants of the once continuous rainforest belt of southwestern Nigeria and supports a rich assemblage of wildlife, significant carbon stocks, and essential ecosystem functions. The reserve also contains habitat for several threatened species and lies within a landscape of growing agricultural and industrial activities, which makes it uniquely vulnerable and ecologically valuable. Encroachment from plantation agriculture, fuelwood extraction, and settlement expansion continues to fragment the reserve and weaken its ecological resilience (Oroka & Ureıgho, 2021).

Effective management is not only hindered by the lack of law enforcement that prohibit forest exploitation but also the lack of consistent, long term, high resolution evidence that captures both the timing and spatial pattern of forest loss and subsequent recovery. This challenge reflects a wider issue in tropical forest monitoring, where different datasets often yield divergent estimates of forest change. These inconsistencies create uncertainty in the magnitude and direction of forest dynamics and complicate conservation planning and policy formulation (Chen et al., 2020).

The development of global, satellite based forest monitoring products has improved the capacity to measure forest change with greater spatial and temporal coherence. Among these, the Hansen Global Forest Change dataset, derived from Landsat imagery at 30 m resolution, is a widely adopted resource for detecting annual forest loss and cumulative forest gain since 2000 (Hansen et al., 2013). Its long temporal coverage and ability to detect small clearings make it particularly suitable for landscapes exposed to frequent low intensity disturbance. Studies across the tropics have demonstrated the value of this dataset for tracking forest degradation and post disturbance recovery (Burivalova et al., 2015; Galiatsatos et al., 2020).

In Nigeria, however, applications of this dataset remain limited. Many existing research on forest degradation relies on vegetation indices such as normalized difference vegetation index or on land use land cover analyses that compare only a few discrete years and ignores annual trends (Olokeogun et al., 2014; Suleiman et al., 2017; Amaechi et al., 2023; Osadolor & Chenge, 2023; Okoduwa & Amaechi, 2024; Chukwu et al., 2024; Akomolafe & Anumeh, 2025). These approaches often fail to capture annual fluctuation and overlook signs of forest gain.

The absence of detailed spatiotemporal assessments in areas such as OFR weakens enforcement systems and constrains evaluation of conservation outcomes. A comprehensive long term analysis of forest loss and gain is therefore needed to provide site specific evidence that can guide targeted, data driven interventions. This study therefore aims to use the Hansen Global Forest Change dataset for the period 2000 to 2024 to quantify annual and cumulative forest loss and gain within OFR. The study offers a multi decade assessment of forest dynamics in one of Nigeria's most important protected landscapes where reliable spatial information has been limited.

By providing a continuous account of how forest cover has changed over time, the results will make visible on maps areas of intensive disturbance and highlight zones of forest regrowth. Forest loss in the OFR is assumed to be spatially clustered, forming zones of intense disturbance, while forest gain is limited, fragmented, and localized in specific areas. Furthermore, it is hypothesized that the current study will reveal a cumulative loss of forest cover that significantly exceeds the cumulative gain over the study period. These assumptions make the current study highly relevant, that is, if the results confirm the hypotheses, it would indicate that:

– the reserve ecosystem is experiencing a persistent net deficit in forest cover that is not compensated for by natural regeneration processes;

– a significant mismatch between forest loss and gain leads to a long-term decline in biodiversity; a weakened capacity of the ecosystem to store carbon, and disruption of key ecological functions, including the maintenance of the interior forest environment;

– in the near term, this will contribute to increased vulnerability of the landscape to further degradation, increased climate risks, and a decrease in the effectiveness of the reserve as a conservation tool.

MATERIALS AND METHODS

Study area

Okomu Forest Reserve (OFR) is located in Edo State, southwestern Nigeria, and lies approximately between latitudes 6°10′ and 6°30′ N and longitudes 5°00′ and 5°30′ E (Figure 1). The reserve contains the Okomu National Park, which represents the core protected area within the broader forest landscape. The OFR covers approximately 108,200 hectares (ha) and is representative of the lowland rainforest ecosystem of southern Nigeria (Onojeghuo & Onojeghuo, 2015; Oroka & Ureıgho, 2021). The forest reserve harbours diverse plant and animal species that are unique to this part of West Africa. Notable fauna include the white-throated monkey (Cercopithecus albogularis), as well as several endangered species such as the African forest elephant (Loxodonta cyclotis), dwarf crocodile, bush cow, leopard, various species of donkeys, a wide variety of monkeys, and numerous other wild animals (Akinsorotan et al., 2011; Enaruvbe, 2018; Oroka & Ureıgho, 2021). The vegetation of OFR is classified as Guinea–Congo lowland rainforest and is characterized by a heterogeneous mosaic of swamp forest, high forest, secondary forest, and open scrub vegetation (BirdLife International, 2011; Onojeghuo & Onojeghuo, 2015). OFR experiences a typical humid tropical climate, marked by two principal seasons: a rainy season and a dry season. The rainy season extends from March to October, whereas the dry season occurs between November and February, with the months of December and January often influenced by the Harmattan winds. The mean annual rainfall in the area is approximately 2,100 mm, and the mean annual temperature averages around 30ºC (Enaruvbe, 2018; Ezenwenyi et al., 2024).

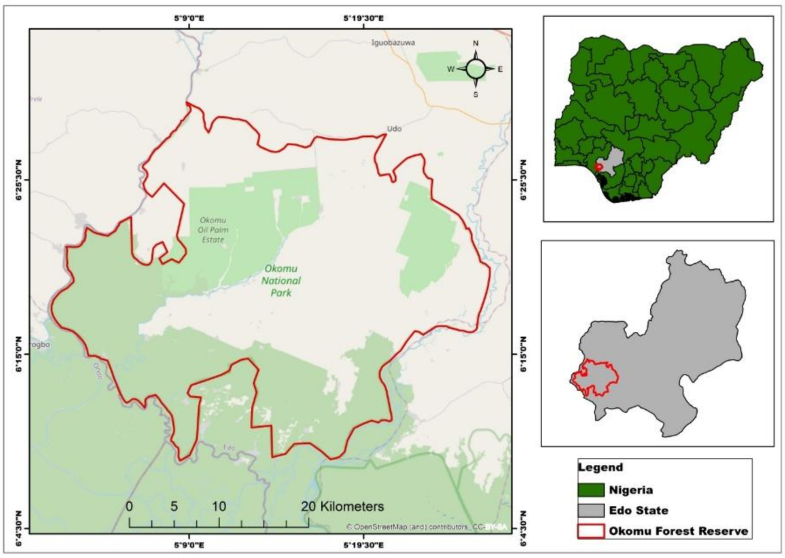

Figure 1. Map showing Okomu Forest Reserve

Study framework and analytical environment

This study used an integrated approach based on remote sensing and geospatial analysis to quantify forest cover dynamics within the Okomu Forest Reserve (OFR) from 2000 to 2024. The analysis aimed to determine spatiotemporal patterns of forest cover, annual and cumulative forest loss, forest gain, and net forest change, providing a holistic understanding of the long-term dynamics of forest ecosystems within the protected area.

All spatial and temporal analyses were performed using the Google Earth Engine (GEE) cloud computing platform, which provides access to extensive satellite data archives and the high-performance computing resources necessary for processing and analysing multi-year time series at regional and local scales (Velastegui-Montoya et al., 2023).

The study area was defined using the vector boundary of the OFR, which was imported into the GEE environment and used as the region of interest (ROI). This boundary was used to spatially clip all datasets used, ensuring consistency in spatial coverage and scale of analysis throughout the study period. This approach eliminated the influence of external areas and focused the assessment solely on processes occurring within the protected area. Figure 2 shows OFR boundary within the GEE environment and the result obtained after processing the dataset.

Dataset description

The dataset used in this study is the Hansen Global Forest Change version 1.12 (2024 update), hosted by the University of Maryland and available within the GEE data catalogue under the identifier UMD/hansen/global_forest_change_2024_v1_12. This dataset is derived from Landsat satellite imagery with a spatial resolution of 30 meters and provides consistent global forest cover and change information from the year 2000 to 2024. The dataset includes tree canopy cover for the baseline year 2000 expressed as percentage cover per pixel, cumulative forest loss mapped annually from 2001 to 2024, forest gain for the period 2000 to 2024, and a lossyear band indicating the specific year in which forest loss occurred. The dataset is widely validated and has been extensively used in peer-reviewed forest monitoring and deforestation studies worldwide (Hansen et al., 2013; Burivalova et al., 2015; Galiatsatos et al., 2020).

In this study, four bands were extracted for analysis, namely treecover2000, loss, gain, and lossyear (Figure 3). The treecover2000 band represents the initial forest condition at the beginning of the study period and forms the baseline for subsequent change detection. The loss band indicates whether a forest pixel experienced stand-replacement disturbance at any time between 2001 and 2024. The gain band identifies areas where forest regrowth occurred over the same period. The lossyear band encodes the year of forest loss for each affected pixel, enabling annual loss trend analysis (Hansen et al., 2013)

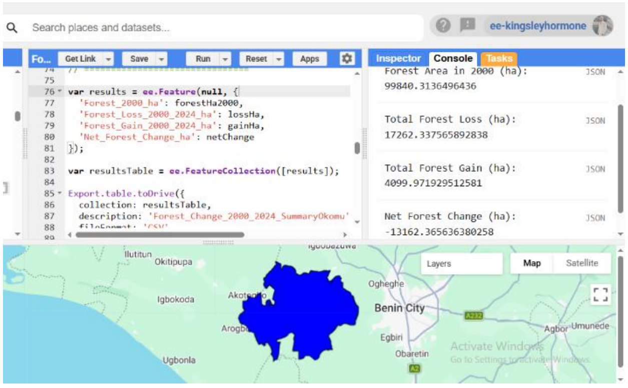

Figure 2. OFR boundary within the GEE environment and the result obtained after processing the data

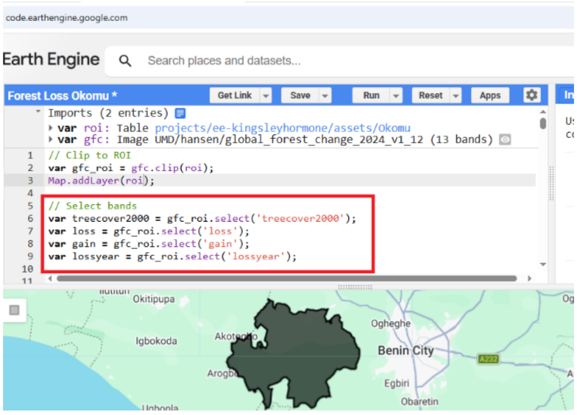

Figure 3. Map showing the selected bands in GEE

Definition of forest and baseline forest cover assessment

To ensure comparability of results with generally accepted international forest monitoring standards, this study used a clear and operationalized definition of forest based on canopy cover. The treecover2000 layer from the Hansen Global Forest Change dataset, which reflects the percentage of canopy cover for each pixel in the base year 2000, was used as the base layer. A minimum canopy cover threshold was set at 30%, at which pixels with canopy cover equal to or greater than this threshold were classified as forest, while pixels with lower values were classified as non-forest.

This threshold is consistent with widely used practice in tropical forest research and has been recommended in several previous studies as a compromise between including degraded forest formations and excluding sparse woody vegetation, shrub communities, and other non-forest cover types (Galiatsatos et al., 2020). Using a single threshold across the entire study area also ensured spatial consistency of the classification and avoided systematic biases in subsequent assessments of forest cover changes.

The baseline forest area for 2000 was calculated by transforming the continuous canopy cover layer into a binary forest mask and then multiplying this mask by the area of an individual pixel, determined by the spatial resolution of the dataset used. The total forest cover area was obtained by summing the areas of all forest pixels within the OFR study area. For ease of interpretation and comparability with other studies, the resulting values were converted from square meters to hectares.

Estimation of total forest loss from 2001 to 2024

To quantify the total forest loss within the study area, the Hansen et al. (2013) global dataset on forest cover loss was utilized as the primary data source. A forest mask for the year 2000 was used as a baseline to identify areas initially classified as forest. A forest loss layer for the period 2001–2024 was superimposed on this mask, excluding all areas classified as non-forest to avoid accounting for changes in non-forest lands, such as agricultural land or urban areas.

To calculate losses spatially explicitly, each pixel in the forest loss layer was multiplied by the area of one pixel (in square meters), which is necessary to obtain local forest loss values. Summing all pixels within the study area boundaries then calculated the total area of forest loss over the observation period. The resulting values were converted to hectares for ease of interpretation and comparison with other regional and global estimates. This approach was chosen to obtain results that reflect precisely anthropogenic or natural deforestation, excluding artifacts associated with changes in non-forest cover types.

Estimation of total forest gain from 2000 to 2024

Forest growth was assessed using the same dataset by Hansen et al., which records areas that transitioned from non-forest to forested areas during the study period. To exclude areas already covered by forest in 2000, the growth layer was masked with the forest mask of the baseline year, as this approach allows for the identification of only new forest formations, including natural regeneration and forest plantings.

After masking, each forest growth pixel was multiplied by its area, yielding spatially explicit growth values. Summing all masked pixels within the study area yielded the total forest growth area for the period 2000–2024. The results were also converted to hectares for standardization and subsequent comparison with forest loss. This methodological approach aims to ensure logical consistency in the analysis, allowing for the distinction between forest loss and forest gain and minimizing potential distortions associated with non-forest land dynamics.

Net forest change analysis

Net forest change was computed as the difference between total forest gain and total forest loss for the period 2000 to 2024. A negative net change value indicates overall forest decline, while a positive value indicates net forest expansion. This metric provides a simplified but robust indicator of the long-term balance between deforestation and forest regeneration within the OFR.

Annual forest loss analysis

To examine the temporal dynamics of deforestation, annual forest loss was computed for each year between 2001 and 2024 using the lossyear band. Sequential filtering was applied to isolate forest loss for each individual year. For each year, the annual loss mask was multiplied by pixel area, and the total area of deforestation was computed within the study boundary. The yearly loss values were converted to hectares and stored as a time-series dataset. These annual loss statistics were then exported in comma-separated values (CSV) format for graphical visualization.

Data export and output generation

To systematize and document the results, all key forest cover indicators were compiled into a structured table. This included the baseline forest area in 2000, total forest loss for the period 2001–2024, total forest gain for the period 2000–2024, and net forest cover change. The table was exported in CSV format, making it convenient for subsequent statistical processing and replication of the analysis.

For time series analysis, annual forest loss values from 2001 to 2024 were also compiled and saved in a separate CSV file. This approach was required to assess deforestation dynamics with annual detail and identify potential trends or anomalies in the study area. The spatial results of the analysis were exported as GeoTIFF raster files with a spatial resolution of 30 m, including: (i) baseline forest cover for the year 2000, (ii) accumulated forest loss for the period 2001–2024, and (iii) forest gain for the period 2000–2024. This was done because such formats ensure compatibility with most geographic information systems and enable cartographic visualization, spatial analysis, and integration with other geodata. ArcGIS version 10.7.1 was used to visualize the final maps, applying standard procedures for displaying raster data and classifying forest loss and gain by area.

Limitations and uncertainty

Despite the robustness of the Hansen Global Forest Change (GFC) dataset used in this study, several limitations and sources of uncertainty should be acknowledged when interpreting the results. First, the Hansen dataset relies on Landsat imagery with a spatial resolution of 30 m, which may not adequately capture small-scale forest disturbances such as selective logging. As a result, some forms of forest degradation that do not lead to complete canopy removal may have been underestimated, particularly in areas subjected to gradual anthropogenic pressure.

Second, forest loss in the Hansen GFC dataset is defined as a stand-replacement disturbance, implying complete canopy removal within a pixel (Tyukavina et al., 2022). This definition does not differentiate between permanent deforestation and temporary forest clearing associated with plantation harvest cycles or shifting cultivation. Consequently, some areas classified as forest loss may represent rotational land-use practices rather than irreversible conversion, potentially leading to an overestimation of long-term forest decline in parts of the reserve.

In addition, the use of a 30% canopy cover threshold to define forest, while consistent with established conventions and previous studies, introduces classification uncertainty, particularly in transitional zones between forest and non-forest land cover. Variations in canopy density near this threshold may result in misclassification, especially in fragmented or degraded forest landscapes common within protected areas experiencing anthropogenic pressure.

Finally, this study did not incorporate field-based validation due to logistical constraints within the reserve. However, the observed spatial and temporal patterns of forest loss and gain are consistent with findings from previous studies conducted in Okomu Forest Reserve and comparable forest ecosystems in southern Nigeria, providing indirect support for the reliability of the results. Nonetheless, future studies integrating field observations would further reduce uncertainty and improve the accuracy of forest change assessments in the reserve.

RESULTS AND DISCUSSION

Table 1 shows that OFR contained 99,840 ha of forest in the year 2000, confirming that the reserve was still heavily forested at the beginning of the study period. Between 2001 and 2024, the reserve lost 17,262 ha of forest, representing a reduction of approximately 17.3% of the baseline forest cover, while only 4,100 ha (about 4.1%) experienced regrowth. This imbalance resulted in a net forest decline of 13,162 ha, equivalent to a net loss of about 13.2% of the original forest extent, indicating a substantial reduction in forest cover. A similar study by Onojeghuo & Onojeghuo (2015) reported a forest loss of approximately 20% of the entire reserve between 1987 and 2011. According to Buba (2019), the high rate of deforestation in OFR is largely driven by intensified agricultural practices and excessive exploitation of forest resources associated with rapid population growth.

The imbalance between loss and gain suggests that disturbance has been consistent, reducing the size, health, and integrity of OFR. Such a decline has major implications for wildlife species that depend on dense, undisturbed forest, including forest elephants, primates, and many bird species. Research argues that wildlife struggle to survive when forests become fragmented or heavily disturbed (Slattery & Fenner, 2021; Tasya, 2025). The loss of old forest also reduces carbon storage, weakens the forest's role in climate regulation, and increases carbon emissions into the atmosphere (Potapov et al., 2017; Li et al., 2022).

Table 2 presents the annual forest loss between 2001 and 2024 and shows that the pattern of loss was not uniform. Several years stand out with very high forest loss, such as 2001, 2002, 2013, 2017, 2018, and 2024. These periods may be as a result of increased agricultural expansion and logging activity in the reserve. Other years, such as 2003 and 2006, show very low forest loss. These moments likely reflect short-lived enforcement improvements or temporary reductions in illegal forest activities. However, since high-loss years consistently reappear, it is safe to say that the protection measures during low-loss years were not strong enough to produce long-term recovery. The increase in loss in 2024 further shows that pressure on the forest remains strong and may even be increasing.

Table 1. Forest area, loss, gain, and net change in OFR (2000–2024)

Forest area (2000)		Forest loss (2001–2024)		Forest gain (2001–2024)		Net forest change	
ha	%	ha	%	ha	%	ha	%
99,840	100	17,262	17.28	4,100	4.11	–13,162	−13.18

Table 2. Annual forest loss (2001–2024)

Year	Forest loss, ha	Year	Forest loss, ha	Year	Forest loss, ha
2001	1,346	2009	347	2017	1,785
2002	1,799	2010	743	2018	1,137
2003	97	2011	445	2019	496
2004	200	2012	910	2020	491
2005	380	2013	1,921	2021	898
2006	184	2014	1,605	2022	659
2007	237	2015	819	2023	441
2008	747	2016	1,042	2024	1,369

The forest cover map for the year 2000 (Figure 4) adds valuable spatial context to the statistical results. The central and southern sections of the reserve appear as a large, continuous mass of thick forest, indicating that these areas were still relatively undisturbed in the year 2000. These intact zones provide core habitat for sensitive wildlife species and maintain stable microclimatic conditions that support high biodiversity (BirdLife International, 2011). In contrast, the eastern and north-eastern edges show lighter patches and gaps, suggesting early signs of disturbance from farming, logging, plantation development, or creation of human settlement. Forest edges are known to experience more human intrusion, which weaken forest structure over time (Onojeghuo & Onojeghuo, 2015). These early openings along the Forest edges or boundary set the stage for the larger forest losses that followed.

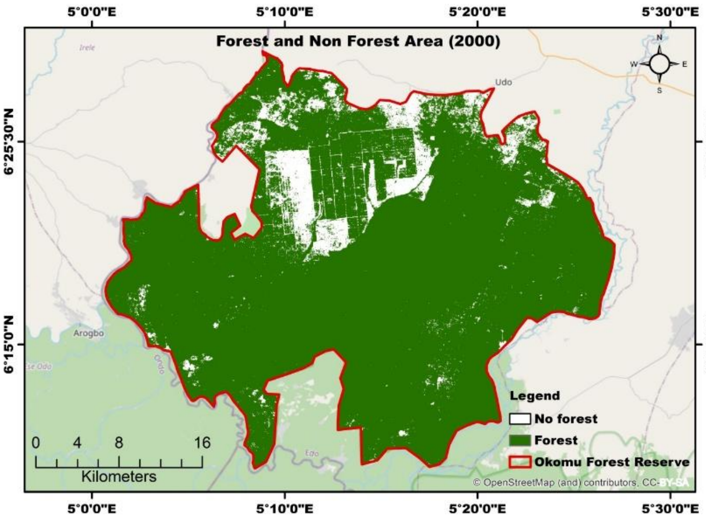

Figure 4. Forest and non-forest area in OFR, 2000

The cumulative forest loss map for the period 2001–2024 (Figure 5) demonstrates the spatial concentration of deforestation and identifies key areas of forest degradation. The highest density of loss is observed along the eastern boundary of the study reserve, where expanding farms, plantations, and built-up areas are gradually encroaching on forested areas. Large clusters of loss in this zone correspond to long-term agricultural pressure noted in previous regional studies (Enaruvbe, 2018).

As shown by Burivalova et al. (2015), forest degradation in protected areas often initiates along access routes, such as roads, trails, or utility lines, which serve as entry points for economic activity. The map obtained in the current study shows that some areas of loss extend inland from the boundary, forming linear paths that likely correspond to old access routes used by loggers or farmers. These lines create an infiltration effect that increases the vulnerability of interior forest areas to fragmentation and further logging.

In addition to large clusters, numerous small and scattered patches of loss are observed within the reserve. These likely represent isolated clearings, temporary farms, or small economic plots that increase forest fragmentation and undermine ecosystem integrity. Fragmentation not only reduces the area of continuous forest but also reduces ecosystem functions, including carbon storage, biodiversity maintenance, and resilience to anthropogenic impacts (Hansen et al., 2013; Curtis et al., 2018).

Similar patterns of degradation have been noted in other tropical regions. For example, research in Southeast Asia and Central Africa suggests that infiltration along borders and roads is a key driver of forest loss, creating linear and isolated clearings that, over time, can lead to the loss of large ecosystem structures (Laurance et al., 2014; Sloan et al., 2018). This confirms that the linear paths and small fragments of loss observed in our study are not random, but reflect systemic degradation processes driven by a combination of accessibility, anthropogenic pressure, and historical land use patterns.

Thus, the forest loss map reveals not only the scale of deforestation, but also spatial patterns that can be used for targeted forest conservation planning. Intense pressure along the boundaries and existing access routes highlights the need for active monitoring, control, and, where necessary, restriction of human access to prevent further degradation of the reserve's interior.

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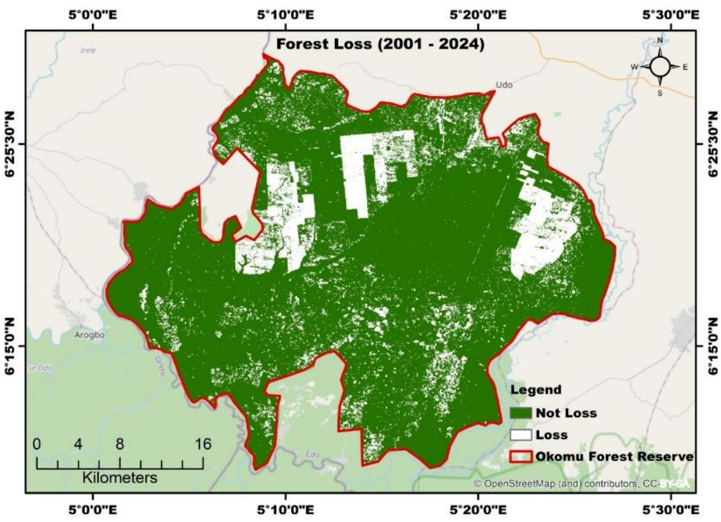

Figure 5. Forest loss in OFR, 2001–2024

An analysis of the spatial distribution of forest growth (Figure 6) shows that forest restoration processes occurred in limited, fragmented areas. The total forest growth for the period 2000–2024 was approximately 4,100 hectares, significantly less than the total forest loss over the same period. The spatial distribution of growth is characterized by high isolation of individual areas, with the highest concentration of restored areas observed in the north-western and southwestern parts of the study area.

These areas likely reflect abandoned agricultural land, temporarily unused land, or areas where human activity was limited for long periods, allowing natural vegetation regeneration. Narrow linear strips of restoration are also observed along some boundaries and small fragments within the reserve where clearings had previously occurred. Despite these signs of restoration, their size and fragmentation make them insufficient to restore the forest's previous ecological function. Young forest stands have limited carbon storage capacity, support lower species diversity, and are more vulnerable to reforestation than mature forests. Consequently, ongoing forest regeneration in the study area does not compensate for the loss of ecosystem functions, biodiversity, and resilience caused by deforestation. The spatial isolation and small size of restored sites highlight the need for active reforestation measures to improve ecosystem integrity and resilience in the region.

When all results are combined, the maps and tables reveal a clear long-term trend of forest degradation. OFR has shifted from a mostly intact forest landscape in 2000 to a more fragmented and forest landscape by 2024. Forest loss has moved inward from the edges, breaking the forest into smaller pieces and reducing the amount of interior forest habitat that many species depend on. This fragmentation increases wildlife vulnerability, allows hunters easier access, and disrupts natural ecological processes. The reduction in mature forest also weakens the forest's ability to store carbon, contributing to climate change and reducing long-term ecosystem stability.

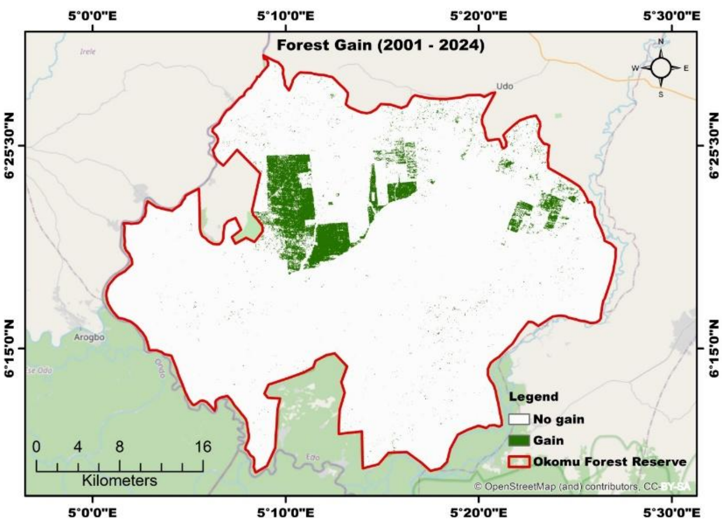

Figure 6. Forest gain in OFR, 2001–2024

These results are consistent with the findings of several previous studies conducted in tropical and subtropical forests. For example, studies by Hansen et al. (2013) and Curtis et al. (2018) show that natural forest regeneration is typically limited to small fragments and rarely compensates for anthropogenic forest cover losses at the landscape scale. Similar observations in Africa, Southeast Asia, and South America demonstrate that fragmented restoration sites have limited capacity to store carbon and support biodiversity until they reach a mature stage (Chazdon, 2014; Poorter et al., 2016).

Thus, despite the presence of distinct restoration zones, the overall ecological value of these sites remains low without large-scale interventions to actively plant forests, expand existing fragments, and create corridors connecting restored and remaining forest areas. These observations emphasize that natural regeneration, while important, cannot fully offset the impacts of deforestation and require integrated management and landscape-level forest restoration planning.

Comparison of forest loss in OFR with other protected forests

To place the forest loss observed in OFR within a broader ecological and regional context, the magnitude and pattern of deforestation documented in this study were compared with findings from other protected forest reserves in Nigeria and Sub-Saharan Africa (Table 3). Such comparisons are essential for determining whether the observed trends in OFR are exceptional or reflective of wider regional dynamics affecting tropical forest conservation.

Observed patterns of forest loss and their ecological implications

The observed pattern of forest loss in OFR has significant ecological implications that go beyond the simple reduction in forest area. Spatial progression of deforestation from the reserve boundaries toward the interior indicates a systematic erosion of forest core areas. These core areas are essential for maintaining stable microclimatic conditions, regulating humidity and temperature, and supporting forest-dependent species. As deforestation penetrates deeper into the forest, its effects become increasingly pronounced, exposing previously intact interior habitats to higher temperatures, reduced humidity, increased wind penetration, and greater human access. These changes contribute to habitat degradation and ecological stress (Potapov et al., 2017; Slattery & Fenner, 2021).

Table 3. Summary comparison of forest loss across selected forest reserves

Reserve / Study area	Period	Loss, %	Source
Okomu Forest Reserve, Nigeria	2001–2024	about 17%	This study
Gazetted Forest Reserves, Nigeria	1986–2020	Risha 88%; Doma 83%; Odu 55%	Chunwate et al., 2025
Ngel Nyaki Forest Reserve, Nigeria	1993–2023	about 80%	Akomolafe & Anumeh, 2025
Ghana's Ankasa (ACA) and Bia Conservation Area (BCA)	1980–2020	ACA 16.4%; BCA 14.4%	Ashiagbor et al., 2024
Okomu National Park, Nigeria	2000–2020	about 22%	Adeniji et al., 2023
Intact Forest Landscapes (Global)	2000–2013	about 7%	Potapov et al., 2017
Falgore Game Reserve, Nigeria	1986–2015	95% of dense woodland area; 37% of moderate woodland area	Suleiman et al., 2017
Shasha Forest Reserve, Nigeria	1986–2010	46%	Olokeogun et al., 2014
Masoala National Park, Madagascar	2000–2012	5–15%	Burivalova et al., 2015

The concentration of forest loss along the eastern and northeastern boundaries suggests that anthropogenic pressure is strongly linked to accessibility and proximity to surrounding human activities. Boundary-driven deforestation is commonly associated with agricultural expansion, plantation development, and illegal logging facilitated by road networks and informal access routes, as widely documented in tropical forest reserves (Burivalova et al., 2015). Such spatially structured forest loss fragments the reserve into smaller and increasingly isolated forest patches, reducing landscape connectivity and restricting species movement. Fragmentation increases wildlife vulnerability by limiting gene flow, decreasing available habitat, and enhancing exposure to hunting and human disturbance, thereby reducing the long-term viability of populations (White & Edwards, 2000; Slattery & Fenner, 2021).

Although forest gain was observed within OFR during the study period, its ecological significance remains limited. Regenerating patches are spatially fragmented and predominantly confined to peripheral or previously disturbed areas, indicating that regeneration occurs primarily through secondary succession. Secondary forests differ substantially from mature lowland in structural complexity, species composition, and ecosystem functioning. Numerous studies have demonstrated that secondary forests typically sequester less carbon, support lower biodiversity, and provide fewer ecosystem services than old-growth tropical forests, even several decades after regeneration (Potapov et al., 2017; Li et al., 2022). Consequently, observed forest gains within the reserve are unlikely to compensate for the ecosystem functions lost due to mature forest removal.

The imbalance between sustained forest loss and limited forest gain suggests that OFR may be approaching an ecological threshold beyond which natural recovery becomes increasingly constrained. Repeated years of high forest loss during the study period indicate persistent, rather than episodic, disturbances. Continuous disturbance disrupts successional processes, prevents forest maturation, and reinforces degradation feedbacks, such as soil exposure, establishment of invasive species, and repeated human intrusion (Burivalova et al., 2015; Potapov et al., 2017). Over time, these processes may shift the reserve from a predominantly intact tropical forest ecosystem toward a degraded and fragmented landscape with reduced ecological resilience.

From a carbon dynamics perspective, ongoing loss of mature forest cover has implications for climate regulation at both local and regional scales. Mature tropical forests serve as major carbon sinks, and their removal contributes to increased carbon emissions to the atmosphere while simultaneously reducing future carbon sequestration potential (Hansen et al., 2013; Li et al., 2022). The limited and fragmented forest regeneration observed within OFR is unlikely to offset these carbon losses. Collectively, the spatial and temporal patterns of forest loss and gain documented in this study highlight not only the magnitude of deforestation within the reserve but also its broader ecological consequences for biodiversity conservation, ecosystem stability, and climate regulation.

CONCLUSION

This study successfully achieved its objective, comprehensively validating initial hypotheses and assumptions by examining long-term forest cover dynamics in the Okomu Forest Reserve from 2000 to 2024 using Hansen Global Forest Change data. The findings demonstrate that the reserve has experienced significant and sustained forest degradation over the past two decades. Despite its protected area status, Okomu has lost over 17,000 hectares of forest, with restoration processes remaining limited and highly fragmented, resulting in a significant net loss of forest cover. Forest loss and fragmentation pose a serious threat to biodiversity conservation, carbon storage, and ecosystem stability in the reserve. These findings highlight the urgent need for enhanced conservation measures, improved forest law enforcement, and optimized protected area management in the region.

At the same time, the study identified certain gaps and unaddressed challenges. In particular, current medium-resolution satellite datasets are limited in their ability to capture small-scale forest disturbances, protected area intrusion, and early signs of illegal activity. Furthermore, data on the social and economic factors influencing deforestation and forest restoration remain limited. These gaps highlight the need to integrate multiple sources of information, including high-resolution drone imagery and ground-based observations, to more accurately understand forest degradation and restoration processes in the Okomu Reserve.

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Author's statements

Contributions

Conceptualization: A.K.O.; Data curation: A.K.O.; Formal and statistical analysis: all authors; Investigation: all authors; Methodology: all authors; Resources: all authors., Writing original draft: A.K.O.; Writing – review and editing: all authors

Declaration of conflicting interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Financial interests

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Data availability statement

The data used in this study are made available upon request from the corresponding author.

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