

Monitoring Tropical Moist Forest Loss in Sierra Leone's Protected Areas: Remote Sensing Insights from the Western Area Peninsula National Park

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Abstract

Deforestation is a global environmental challenge that threatens food security, resilience, and disaster risk reduction. By disrupting vital ecosystem services like clean water provision, fertile soil maintenance, and climate regulation, it heightens the ecosystem and human population vulnerability to natural hazards such as floods, landslides, and droughts. Sierra Leone's Western Area Peninsula National Park (WAPNP) exemplifies these challenges. Despite full legal protection since 2012, illicit land appropriation, mining, and logging are jeopardizing ecosystem integrity. The limited uptake of institutional enforcement measures and digital technologies in conservation further reduces management effectiveness. This study assesses the extent of WAPNP's closed canopy tropical moist forest cover, one of the last remaining primary forest patches in the country and habitat of the critically endangered western chimpanzee (*Pan troglodytes verus*). The study uses Sentinel-2 satellite data to map forest cover and extent changes from 2020 up until the start of 2024, supplemented by very-high-resolution imagery for validation and accuracy assessment. The results demonstrate their application and effectiveness to uncover the spatial forest cover loss dynamics of closed-canopy forest in Sierra Leone, revealing recent changes in a key protected area. The study findings contribute to a growing body of research advocating full exploitation of the Copernicus Sentinel-2 satellite imagery and open access ancillary forest-related datasets in optimizing land cover classification and forest monitoring. Moreover, the findings provide useful insights for integrating remote sensing tools into conservation efforts and Nature-based Solutions initiatives, supporting more informed and effective ecosystem monitoring and management strategies.

1. Introduction

Forests are among the world's most important ecosystems, offering a variety of critical functions that directly and indirectly benefit human well-being. These include climate and air quality regulation, clean water provision, soil fertility maintenance, as well as food and resource provision (Roe et al., 2021). Forests have an important contribution to global climate stability by functioning as carbon sinks, buffering the consequences of climate change, and increasing ecosystem and human population resilience to climatic shocks (Frey et al., 2016; WRI, 2023; Taylor and Rising, 2021). However, global deforestation and forest degradation have reached critical levels, especially in developing countries where unsustainable farming practices, logging, and infrastructural expansion are causing rapid loss.

West Africa is home to the Upper Guinean Forest Block, an internationally recognized biodiversity hotspot, characterized by dense tropical evergreen rainforest, moist deciduous forest, and a closed canopy cover (White, 1983; USGS, 2018). These forests, however, are also considered to be among the most threatened and fragmented in the world (CILSS, 2016) (Fig. 1). Rapid urbanization, natural resource exploitation and agricultural expansion have resulted in the loss of more than 90% of the original forest system, leaving highly degraded remnants, with only half of it under some form of protection (CILSS, 2016; Brandt et al., 2017). Commercial logging followed by slash-and-burn agriculture has historically driven large-scale deforestation, evermore exacerbated by rapidly increasing population pressure (CI, 2000).

Sierra Leone is no exception. As a member of the Upper Guinean Forest system, rising land demand has placed severe pressure on forested ecosystems, even within nationally designated protected

areas (PAs), which contain most of the country's remaining primary forests, today less than 5% of the original extent (CI, 2000; Brncic et al., 2010).

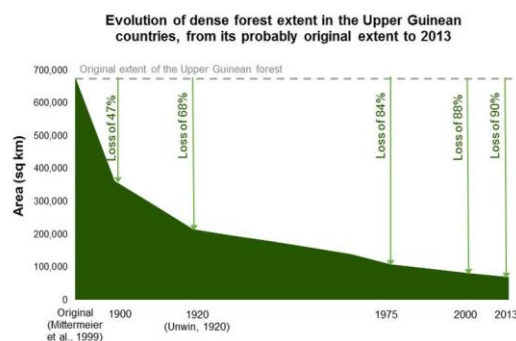


Figure 1. Evolution of dense forest extent in the Upper Guinean countries, from its probably original extent to 2013 (Earth Resources Observation and Science (EROS) Center) (Humble et al 2016).

A prominent example of this can be observed in Sierra Leone's Western Area Peninsula National Park (WAPNP), a protected biodiversity hotspot that is facing growing threats from urban and agricultural expansion, illegal logging, and other human-caused pressures (Brncic et al., 2010). Despite legal protection, human encroachment and natural resource overexploitation, together with limited institutional enforcement measures, continue to fragment these ecosystems, threatening the limited remaining habitat for key local wildlife, including the critically endangered western chimpanzee (*Pan troglodytes verus*) (CILSS, 2016; Humle et al., 2016; Garriga et al., 2019; IUCN, 2022). Further,

these actions largely contribute to the loss of crucial ecosystem services that local communities depend on (Zeynab et al., 2024).

There is ample evidence worldwide demonstrating that the effective establishment and management of PAs has been crucial to preserving biodiversity and the integrity of key ecosystems (Geldmann et al., 2013; Rogers et al., 2022). In Sierra Leone, the Gola Rainforest National Park in the south-east can be considered a success, largely attributable to substantial international funding and implementation of REDD+ (Reducing Emissions from Deforestation and Forest Degradation) (Wadsworth et al., 2019; Bakarr et al., 2022).

PAs have been widely adopted as key Nature-based Solutions (NbS) due to the essential ecosystem services they provide and the damage they help avoid (Lipka et al., 2023) (Fig. 2). The aim of NbS is to address critical societal concerns such as climate change, food security, water security, human health, disaster risk, and social and economic development, through the effective conservation, management, and restoration of natural and modified ecosystems (Roe et al., 2021). In this way, forest conservation and sustainable management initiatives with an NbS approach, are proposed as tools to help create a sustainable future where both nature and people can thrive. Accordingly, international organizations, even when not explicitly focused on nature conservation, are increasingly implementing programs that integrate NbS strategies. One clear example is the World Food Programme (WFP), the world's largest humanitarian organization, which, in its commitment to achieving zero hunger integrates ecosystem restoration together with food security and climate resilience initiatives (WFP, 2024).

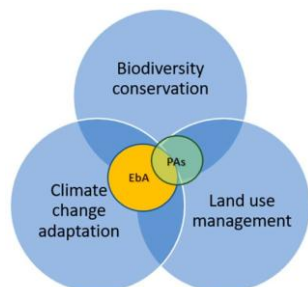


Figure 2. A conceptual model for integrating protected areas into land use system, nature-based solutions, and climate change adaptation (Lipka et al., 2023).

In Sierra Leone, where rural livelihoods are inextricably tied to ecosystem health, effectively integrating NbS into conservation and development strategies is essential. However, outdated and scarce data availability hamper effective conservation efforts. Difficult terrain conditions, limited access to high-quality satellite-derived data, and gaps in local capacity hinder effective forest monitoring. In fact, the last national forest inventory was conducted in 1975 (Brncic et al., 2010; Hosonuma et al., 2012; Wadsworth and Lebbie, 2019), and it is estimated that Sierra Leone has lost around 36% of its forest cover since then, with degraded secondary forests, known as 'Farm-Brush,' now dominating the landscape (Humle et al., 2003; CILSS, 2016). Additionally, the lack of integration of socioeconomic data complicates a deeper understanding of the deforestation drivers.

According to IUCN Global Standard for NbS, to ensure that these solutions are tailored to the unique challenges of the environment and can deliver tangible benefits to both ecosystems and human communities, a critical first step is to have a comprehensive

understanding of the ecosystem's current condition and degradation drivers (Hosonuma et al., 2012; Lo et al., 2023). Updating forest cover estimates and identifying the main causes of degradation and loss is therefore crucial for improving environmental management and fostering effective conservation planning.

Remote sensing technologies are highly effective for monitoring forest cover and identifying drivers of deforestation (Shapiro et al., 2023; MDPI, 2023). Satellite imagery enables large-scale, high-resolution mapping of forest ecosystems, providing timely insights into land-use changes and facilitating the creation of evidence-based conservation strategies, which is particularly important in rapid-changing and data-scarce countries such as Sierra Leone.

This study assesses the current state of Sierra Leone's protected tropical moist closed canopy forests, with a focus on the WAPNP. Using Sentinel-2 (S2) imagery with very high-resolution imagery, field data and canopy height datasets, it provides a recent, spatially explicit assessment of the forest extent and identifies key anthropogenic drivers of forest loss. In doing so, it addresses a critical data gap in a data scarce region applying a cost-effective and replicable remote sensing workflow. The findings further support the development of NbS, linking remote sensing analysis to actionable conservation planning, as well as contributing to the increasing body of knowledge of geospatial research on forest conservation in West Africa.

2. Methodology

Remote sensing techniques were employed to comprehensively assess forest cover loss within the WAPNP from 2020 up until the start of 2024. The primary data source was Sentinel-2 (S2) imagery, which facilitated the derivation of vegetation estimates and the detection of negative changes in forest cover. S2 processing was fully performed in Google Earth Engine (GEE) (Gorelick et al., 2017) (Fig. 3). This data was validated with Very High-Resolution imagery from sources such as Planet and Maxar, together with drone imagery and data collected in the field. In addition, ancillary data, including the JRC Tropical Moist Forest product (Vancutsem et al., 2021), a canopy height map (Tolan et al., 2024) and the NASA FIRMS fire hotspot product (VIIRS) supported the analysis (NASA, 2020). The integration of these data sources provides a comprehensive understanding of the changes occurring within the forest ecosystem.

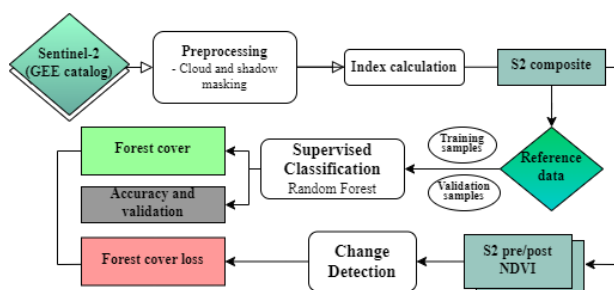


Figure 3: Workflow overview.

2.1 Study Area

Sierra Leone's moist tropical climate, with annual seasonal rainfall ranging from over 3,000 mm in the southwest to roughly

2,000 mm in the north, leads persistent precipitation and cloud cover for most of the months between June and November (wet season).

The Western Area Peninsula National Park (WAPNP), declared a national park in 2012, exemplifies a critical case study of the multifaceted challenges faced by PAs in the country. The WAPNP, spanning approximately 18,000 hectares (ha), is situated in the Western Province, bordering the country's capital, Freetown (Fig. 4). It is part of the western edge of the Upper Guinean Forest Block, characterized by moist equatorial forests which support 80% of Sierra Leone's terrestrial biodiversity, including endangered species like the western chimpanzee (*Pan troglodytes verus*) and the Jentink's duiker (*Cephalophus jentinki*). The national park also plays a critical role in providing fresh clean water from the Guma and Gola reservoirs, the main source for the population in surrounding towns, including the capital, Freetown. The national park, despite its high importance, faces significant threats from human activities, exacerbated by the lack of effective institutional protection mechanisms (Fayiah et al., 2022).

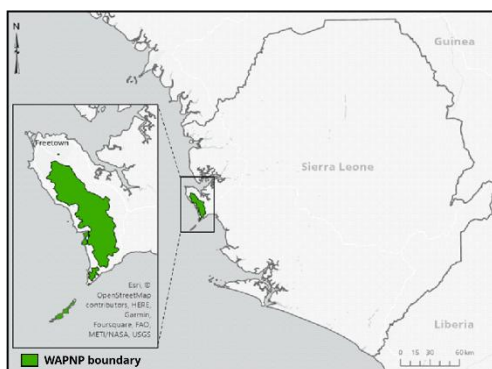


Figure 4: Map of Sierra Leone highlighting the WAPNP's location.

These pressures have led to considerable forest degradation, compromising the park's ability to protect endangered species and maintain ecological stability. Furthermore, the increasing extent of forest loss along its steep hillsides, together with unsustainable land-use practices, is deeply impacting on the terrain stability, as evidenced by the worst landslide and flooding event in the country's history in 2017 (Modugno et al., 2022). This event, which took place in the northern border of the park, resulted in significant loss of life within the adjacent communities (World Bank Group, 2017).

This situation underscores the urgent need for integrated, data-informed sustainable management approaches supporting conservation and monitoring of ecosystem integrity, while addressing the socio-economic needs and long-term resilience of local communities. In this context, WAPNP serves as a critical case study for the application of remote sensing techniques to effectively monitor deforestation and land cover dynamics in Sierra Leone, highlighting the importance of geospatially informed and integrated conservation strategies that balance environmental protection with community needs and livelihoods.

2.2 Data Sources

2.2.1 Satellite Data

This study uses Sentinel-2 (S2) surface reflectance (SR) harmonized data to analyse forest cover in the WAPNP. The S2 mission consists of two satellites, S2A and S2B, with a 5-day

revisit frequency that enables high-resolution, multi-spectral imagery for detailed land cover classification and condition analysis (ESA, 2024). For exact measurements, key spectral bands (such as B2, B3, B4, B5, B8, B8a, B11 and B12) were used and, where necessary, resampled to a resolution of 10 m. Sierra Leone's rainy season, which runs from June to November, imposes a limitation to optical sensors due to frequent cloud cover. This study tackles this restriction by selecting cloud-free images collected during the dry months (December to May) and filtering for imagery with less than 30% cloud cover.

Furthermore, to provide cloud-free composites, a cloud masking technique based on the GEE Landsat cloudScore algorithm and the Temporal Dark Outlier Mask (TDOM) is utilized, which allows for correct data by masking of clouds and shadows (Foga, S. et al., 2017). In some circumstances, median composites of multiple images are used to reduce outliers and residual artifacts. The study produces nine spectral indices from the S2 composites, which are useful for classifying landcover and, identifying vegetation at different conditions. The derived indices were: SR (simple ratio), R48 (red/nir ratio), R118 (swir/nir ratio), NDVI (Normalized Difference Vegetation Index), EVI (Enhanced Vegetation Index), LAI (Leaf Area Index), NDMI (Normalized Difference Moisture Index), OSAVI Optimized Soil-Adjusted Vegetation Index), MNDWI (Modified Normalized Difference Water Index) and LSWI (Land Surface Water Index). Water pixels are masked using an MNDWI threshold to improve classification accuracy (Yancho et al., 2020).

2.2.2 Ancillary Data

To enhance the analysis, several ancillary data sources are incorporated. A global canopy height and a tree cover product are selected from a set of open access datasets (Moudry et al., 2024). For the canopy height dataset, a visual inspection of the site was performed with the S2 false-color composite of the date of interest (January 2nd, 2020) (Fig. 5). This process made the selection of the most fitted product with the observed land cover, considerably clear. The Global Tree Canopy Height Maps (Tolan et al., 2024), developed by Meta and WRI provide 1m resolution tree height data derived from millions of cloud free satellite images, with 80% of the imagery is from the 2018–2020 period) (Moudry et al., 2024).

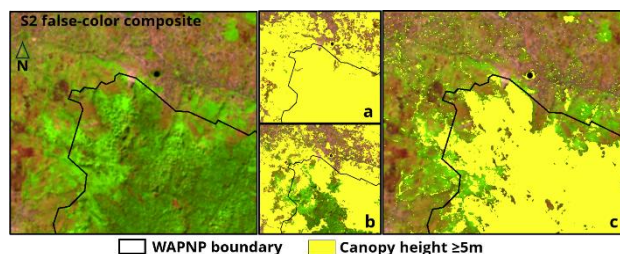


Figure 5. Comparison of a false-color composite highlighting vegetated areas (green) with three global canopy height products showing canopy above 5m: a. Potapov et al. (2021) (30m), b. Lang et al. (2023) (10m); and c. Tolan et al. (2024) (1m).

The JRC Tropical Moist Forest (Vancutsem et al., 2021) product, at 30 m resolution, is used to compare with the forest baseline outputs (Fig. 6). Finally, the VIIRS Fire Hotspot product helps identify disturbance in near-real-time manner, highlighting uncontrolled fire that may be driving forest cover loss within WAPNP.

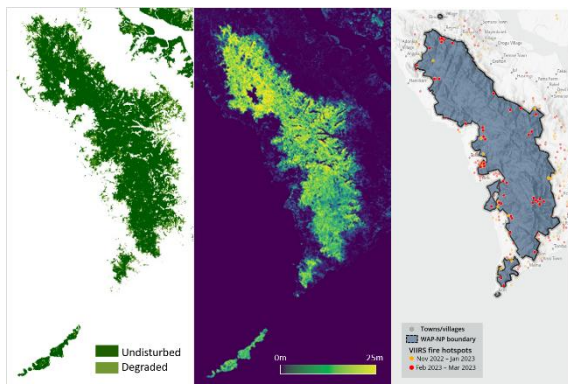


Figure 6: JRC TMF forest cover in 2020 (left) adapted from Vancutsem et al. (2021) and canopy height map (middle) (Tolan et al., 2024), and VIIRS hotspot map (December 2023-March 2022) (right) over the Western Peninsula.

2.3 Analytical methods

2.3.1 Forest cover baseline generation

The forest definition used in this study is consistent with those established by the Food and Agriculture Organization (FAO, 2018) and the EUDR (Article 2(4)) regarding satellite imagery analysis. Forest is defined as an area larger than 0.5 hectares, with trees taller than 5 metres and a canopy cover of more than 10%, or trees capable of reaching these thresholds in situ, excluding land that is predominantly under agricultural or urban land use (EC JRC, 2020). These criteria were applied to refine the classification results where data constraints permitted (EC JRC, 2024).

The establishment of a forest cover baseline is a crucial reference point for understanding subsequent changes. This was conducted using Random Forest (RF) supervised classification. A January 2020 S2 composite was used as an input dataset for training the model. Training data samples were derived from VHR satellite imagery and field data collection to accurately classify forested and non-forested areas. Due to the diversity of the landscape and species composition, attention was invested in selecting a high variation of well distributed training sites of forested (above 5m canopy) and non-forested areas. Priority was given to those sites that presented the least uncertainty. Polygons for both classes were drawn from which training samples were extracted based on a random stratified design. A total of 1000 training samples were randomly generated for each class, from which 300 were reserved for validation. All training points were visually inspected to confirm correct class assignment and broad spatial coverage.

2.3.2 Forest cover loss assessment

To assess changes in forest cover over the study period, S2-based Normalized Difference Vegetation Index (NDVI) layers of different time steps were generated for deriving vegetation estimates (Maselli, 2004). Although NDVI values are influenced by multiple factors such as climatic variability and phenological dynamics, this index has been widely used in forestry and land cover analysis, providing valuable insights into vegetation health and environmental changes across large spatial and temporal scales. The NDVI differencing technique, although simple, is widely applied in remote sensing research (Huang et al., 2020). It provides a reproducible and operationally efficient approach to identify patterns of vegetation disturbance, particularly when

interpreted with strong local contextual understanding, allowing researchers to monitor and detect areas of forest cover loss (Fig. 7). To ensure robustness, changes were validated on-site observations and against VHR imagery from Planet and Maxar.

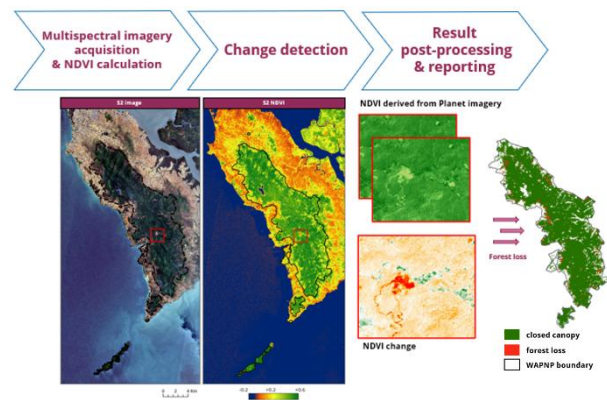


Figure 7. Change detection process.

2.3.3 Key driver identification

Identifying key drivers of forest cover loss involved a multi-faceted approach, utilizing Very High-Resolution (VHR) inspections in conjunction with VIIRS fire hotspots data, as well as ground data collection and validation. These methods permit to pinpoint specific anthropogenic activities and environmental factors contributing to deforestation, thereby providing a clearer understanding of the pressures faced by the national park.

2.4 Data validation

The validation process involves both VHR inspection and ground truthing. The results are compared with VHR satellite-derived data and on-site observations collected from colleagues in the field over different time periods and years. This step is a critical component of this study, ensuring the reliability of our findings. Participatory mapping, was integrated into the data collection process, allowing local stakeholders to contribute valuable insights that enhance the robustness of our assessment. Field activities included GPS collection of deforested areas and land cover information, supplemented by drone imagery to capture detailed visual representations of the landscape, and corroborate drivers of change.

The accuracy of the classification is assessed using a confusion matrix (or error matrix). This commonly used approach compares the relation between the validation (ground truth) data and the corresponding classification results. In this study a total of 300 samples per class are used for validation. By setting a lower number of validation samples compared to training samples, the chances of overlapping points were reduced (Anaya et al., 2020). A visual inspection is also performed. By integrating ground-based data with satellite information, we enhance our understanding of forest cover dynamics and the ecological implications of observed changes.

3. Results

3.1 Forest cover baseline 2020

Our analysis indicates that at the start of 2020 the tropical moist forest covered approximately 14,700 ha (Fig. 8). This means that approx. 82% of the total park extent (18,000 ha) was covered by closed canopy tropical moist forest at this time.

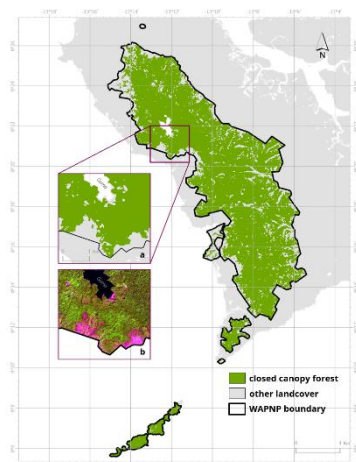


Figure 8. Map of forest cover within WAPNP at the start of 2020. A close-up view is shown in **a**. classified forest cover below Guma reservoir; **b**. S2 false-colour composite highlighting forested areas in green, over the same area.

The derived forest cover layer was compared with two global forest distribution datasets. Overall, the resulting forest extent estimate revealed a lower coverage than those determined by Vancutsem et al. (2021) and Tolan et al. (2024) in their forest distribution studies. The fact that the models of these products are trained and validated at global scale, and use different methods and resolutions, to this study, may partly explain the difference in extents. This can lead to lower accuracies of the global datasets in specific regions. Moreover, in the case of Tolan et al. (2024), although 80% of imagery is taken from 2018 to 2020, images included in the model training range from 2009 to 2020, which means the dataset is not representative of a specific year (Moudry et al., 2024). The JRC TMF dataset from Vancutsem et al. (2021) on the other hand, is based on Landsat imagery (30 m), which offers a lower resolution classification with potentially missing details in the classification (e.g fragmentation from road development, loss along the forest patch edges), and it does not set a minimum height threshold which at a global scale may lead to overestimation of forest cover on a local scale.

Due to differences in geographic coverage and scope, these global datasets are not used to assess the classification model's accuracy. However, they provide a qualitative reference to identify areas that may require closer examination and to corroborate regions consistently classified as forest cover across all datasets.

3.2 Forest cover loss from 2020 to 2023

Between 2020 and 2023, WAPNP experienced notable forest cover loss (Fig. 9). The analysis indicates a total decline of approx. 2,224 ha, translating to an average annual loss rate of 4% in the last four years. The remaining forest cover extent (12,479 ha, at the start of 2024) was compared to the tree cover extent in 2012 recorded by JRC TMF product undisturbed tree cover class (Vancutsem et al., 2021) within the WAPNP in 2012 (17,314 ha), resulting in an estimated 27.93% forest cover loss since the area was formally designated a national park (Table 1).

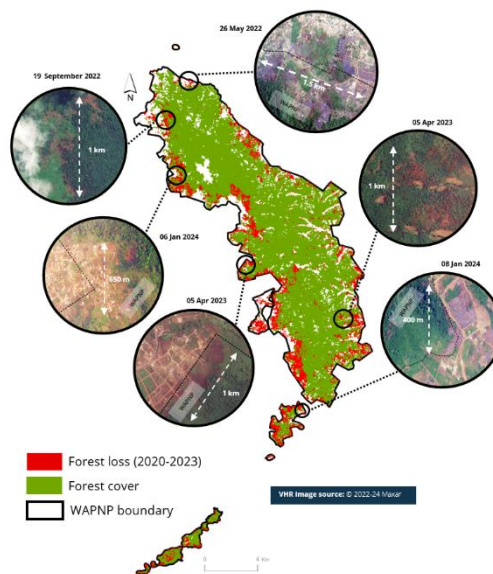


Figure 9: Map showing forest cover loss since 2020 (red) and the remaining forest cover (green), with Maxar VHR captions showing burnt areas and urban expansion into the park.

Annual forest cover loss since 2020				
Year	Total Forest cover (ha) - Jan	Annual cover loss	Loss rate %	Loss since 2012
2020	14703	128	0,87%	15,82%
2021	14575	455	3,12%	18,45%
2022	14120	891	6,31%	23,59%
2023	13229	750	5,67%	27,93%
2024	12479			

Table 1: Summary of deforestation estimates and loss rates over time, providing a quantitative overview of forest cover changes.

3.3 Key drivers of forest cover loss

The analysis identified several key drivers of current forest cover loss, initially validated using Planet and Maxar VHR imagery, along with NASA's FIRMS fire hotspot product, and further supported by ground truthing. Ground truthing activities were performed in dry months of 2023 and 2024. Drone footage was collected in both photo and video format of extensive areas affected by anthropogenic activities, and multiple geolocated photos were captured around the park boundary (Fig. 10). Most of the areas were affected by human-induced forest fires, followed by land grabbing for settlement and agricultural and illicit cropland expansion, as well as extensive quarrying activity and small-scale coal production.



Figure 10: Map displaying ground truthing photo collection sites used to validate deforestation hotspots and identify loss drivers,

alongside selected drone images from WAPNP, supporting study findings.

3.4 Accuracy

The accuracy assessment of the 2020 forest cover baseline result revealed an overall accuracy of 94% in classifying forest cover and non-forest cover. Validation sampling areas were generated taking into consideration known forested areas distributed throughout the park. The S2 model was able to distinguish forest cover quite effectively, with a 95% accuracy for the forest class. It had a higher tendency to misclassify non-forest pixels into forest pixels, which was reflected in the 93% producer's and consumer's accuracy for the non-forest class.

4. Discussion

This study reveals the alarming rate of forest cover loss in WAPNP, which is caused primarily by slash-and-burn agricultural expansion, urbanization, illicit mining and logging activities. A comparison with 2012 forest cover data from Vancutsem et al. (2021) reveals a total forest cover loss of 27.9% by the start of 2024: 15.8% loss is observed by 2020 and an additional 12% in the last four years. This trend demonstrates the ineffectiveness of conservation measures implemented since the park's designation in 2012. Similar deforestation patterns and drivers are evident throughout the Upper Guinean Forest region, with PAs in Guinea experiencing a loss of approx. 18% between 2000 and 2018 (Fitzgerald et al., 2021), but also in other African regions like the Congo Basin, where high rates of loss and fragmentation are predominantly caused by agricultural expansion (Reiche et al., 2021; Shapiro et al., 2023; Tchana et al., 2023).

The severity of deforestation in WAPNP highlights the necessity for policies that effectively combine forest protection with community engagement. Reforestation activities within and beyond park borders, for example, can help stabilize soils, minimize landslide hazards, and increase carbon sequestration while also providing local communities with sustainable livelihood options (Lipka et al., 2023). Effective interventions must rely on standardized, locally developed, and frequently updated forest monitoring systems to guide policies and assess outcomes (Roe et al., 2021).

Achieving successful conservation requires aligning NbS with community needs, improving governance, and fostering collaboration between government agencies, NGOs, and local stakeholders (Hosonuma et al., 2012).

While this study provides a robust, high-resolution assessment of forest cover change, several limitations must also be acknowledged. For instance, although NVDI-based change detection provides an insightful and reproducible approach, particularly in data-scarce regions, caution must be taken when interpreting negative NDVI change as a direct indicator of vegetation cover degradation or loss. Thresholds should be carefully identified, and results should be combined with ground truth observations and expert knowledge. Likewise, more advanced approaches that better account for temporal variability and other dynamics should be considered for future analysis. Despite considerable effort was made to ensure high distribution of training points throughout the study area, the classification relied on a single training/validation split. This approach may lead to an overestimation of accuracy due to spatial autocorrelation when points are clustered. Future studies could strengthen inference by adopting spatially explicit evaluation

methods (e.g. blocked cross-validation). Further, the study's reliance on remote sensing data and ancillary datasets introduces potential uncertainties in estimating forest cover changes in highly fragmented forest patches, and areas with steep or shaded slopes, dense cloud cover or limited ground truthing. Moreover, thematic details should be enhanced to quantify the impact of specific deforestation drivers and to accurately associate them with individual patches of cleared forest (Curtis et al, 2018). Addressing these uncertainties through advanced remote sensing techniques and participatory field validation will be crucial for ensuring the scalability and sustainability of forest management systems.

5. Conclusion

Sierra Leone, like other West African countries, has been experiencing a rising demand on land and natural resources, which has placed a severe pressure on its vital forested ecosystems. These ecosystems are not only biodiversity hotspots, home to several endangered species, but also provide essential ecosystem services to the local communities. The country's vulnerability to climate change, exemplified by events such as the 2017 Freetown landslide, underscores the critical importance of sustainable land management. Alarming, significant human-caused forest cover loss is also being experienced within areas that are legally protected, such the Western Area Peninsula National Park (WAPNP). This analysis demonstrates severe, accelerated forest degradation in the WAPNP since its designation in 2012, driven by urbanization, agricultural expansion, mining, logging, and charcoal production.

The findings emphasize the need for urgent and coordinated conservation efforts and robust protected area management policies. Beyond WAPNP, the study offers valuable insights for forest monitoring in similar contexts, stressing the need for integrating well-designed Nature-based Solutions (NbS) into national policies, supported by reliable, locally informed monitoring systems and active community engagement. Future efforts should prioritize scalable, inclusive strategies that align conservation goals with local development necessities. Leveraging advancements in remote sensing data and participatory methods will be key to establish reliable forest baselines and monitor changes overtime, as well as to plan and evaluate the impacts of future NbS interventions.

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