

**BEYOND FOREST EXTENT: A GLOBAL GEOGRAPHICAL ASSESSMENT OF FOREST LANDSCAPE STRUCTURE, COMPOSITION, AND POST-2020 TREE-COVER LOSS****Dr. Narinder Kaur** Independent Researcher

**ABSTRACT** Global assessments of forest resources have traditionally emphasized forest extent, yet forest area alone does not adequately describe the spatial configuration, composition, or recent tree-cover loss of forest landscapes. This study develops a global geographical assessment framework that integrates forest landscape structure, forest type, and post-2020 tree-cover loss. A 2020 forest baseline was established using Global Forest Cover 2020 (GFC2020), landscape structure was characterized using forest opening size (FOS) and forest area density (FAD), and forest composition was assessed using Global Forest Types 2020 (GFT2020). Detected tree-cover loss during 2021–2025 was quantified using UMD/Hansen Global Forest Change 2025 (GFC2025) for 276 geographical units. QGIS and Google Earth Engine were used for spatial processing and large-scale aggregation. Spearman analysis showed that cumulative loss was strongly associated with total forest area, while relative loss showed different relationships with forest extent and forest-type composition. Multivariate models using log-transformed loss outcomes and baseline forest characteristics showed strong positive associations of total forest area with absolute and relative loss, while naturally regenerating and primary forest percentages showed negative coefficients after accounting for the other predictors. Results were directionally stable in sensitivity analyses using a minimum forest-area threshold and an upper-tail exclusion. Globally, naturally regenerating forest represented 56.17% of mapped forest, primary forest 36.96%, and planted/plantation forest 6.86%. Cumulative detected tree-cover loss during 2021–2025 reached 13.24 million km<sup>2</sup> across the geographical units, although the magnitude and proportional loss varied substantially among them. The study demonstrates that forest extent, spatial configuration, forest composition, and recent detected tree-cover loss provide complementary geographical information and should not be reduced to a single indicator. The framework provides a reproducible basis for global forest monitoring and spatially differentiated geographical assessment.

**KEYWORDS :** Forest Landscape Structure; Forest Composition; Tree-Cover Loss; GIS**1. INTRODUCTION**

Forests are fundamental components of terrestrial ecosystems, supporting biodiversity, carbon storage, climate regulation, hydrological processes, and a wide range of ecosystem services. Global forest assessments have traditionally emphasized forest extent; however, forest area alone does not adequately describe the spatial organization, composition, or recent disturbance of forest landscapes. Geographical units with comparable forest areas may differ substantially in fragmentation, spatial configuration, forest composition, and exposure to subsequent disturbance (FAO 2020; Haddad et al. 2015).

The increasing availability of satellite-based Earth-observation datasets has improved the capacity to characterize forest extent and change consistently across large geographical areas. Global forest-change products provide important information on the spatial and temporal distribution of tree-cover disturbance (Hansen et al. 2013). However, detected tree-cover loss should not automatically be interpreted as permanent deforestation because it may result from different processes, including harvesting, fire, and land-use conversion (Curtis et al. 2018). Therefore, geographical assessments benefit from distinguishing baseline forest structure and composition from subsequent observations of tree-cover loss.

Forest fragmentation is an important dimension of landscape structure because the subdivision of continuous forest can increase edge exposure and alter habitat configuration and ecological processes (Haddad et al. 2015). Forest composition provides another dimension, as naturally regenerating, planted/plantation, and primary forests represent different ecological and management contexts. Despite advances in global forest monitoring, these dimensions are often assessed separately.

This study develops an integrated geographical framework combining Global Forest Cover 2020 (GFC2020), forest opening size (FOS) and forest area density (FAD), Global Forest Types 2020 (GFT2020), and UMD/Hansen Global Forest Change 2025 (GFC2025). The study aims to characterize global forest landscape structure and composition and examine the geographical distribution of detected tree-cover loss during 2021–2025. It further evaluates associations between baseline forest characteristics and subsequent detected loss using correlation and multivariate analysis. The study therefore examines forest landscapes beyond forest extent and provides a reproducible geographical framework for integrating spatial configuration, forest composition, and recent tree-cover disturbance.

**2. MATERIALS AND METHODS**

The study used a global geographical framework covering 276 geographical units. Global Forest Cover 2020 (GFC2020 V3) was

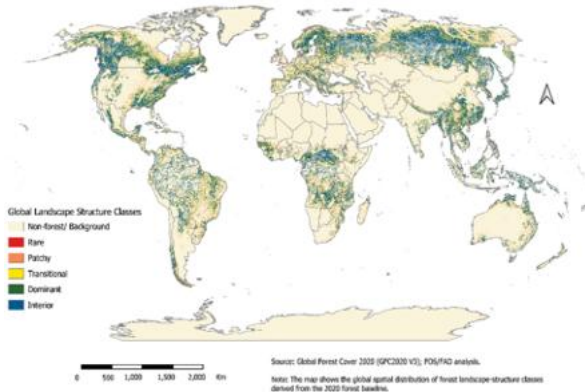
used as the 2020 forest baseline (Bourgoin et al., 2026b). Forest landscape structure was characterized using Forest Opening Size (FOS) and Forest Area Density (FAD) at 100 m resolution in the ESRI:54052 World Goode Homolosine equal-area projection. The resulting landscape structure was classified into five forest classes Rare, Patchy, Transitional, Dominant, and Interior representing a gradient from fragmented to increasingly continuous forest configurations.

Forest composition was assessed using Global Forest Types 2020 (GFT2020 V1), distinguishing naturally regenerating, planted/plantation, and primary forest (Bourgoin et al., 2026a, 2026b). Their areas and proportional contributions were calculated for the geographical units. Detected tree-cover loss during 2021–2025 was derived from UMD/Hansen Global Forest Change 2025 (GFC2025 V1.13). Annual loss observations were aggregated to a 1-km analytical grid and then summarized by geographical unit. Loss was expressed both as cumulative area and relative to baseline forest area. Detected tree-cover loss was treated as a disturbance indicator rather than automatically as permanent deforestation.

Spatial processing and mapping were conducted using QGIS 3.44.12, while Google Earth Engine (GEE) was used for large-scale GFC2025 processing and geographical aggregation. Descriptive statistics and Spearman's rank correlations were used to examine relationships between baseline forest characteristics and subsequent detected loss. Multivariate ordinary least-squares models with HC3 robust standard errors were estimated for log-transformed absolute and relative loss. Predictors included total forest area, naturally regenerating forest percentage, and primary forest percentage, with planted/plantation forest as the reference component. Sensitivity analyses applied a minimum forest-area threshold of 100 km<sup>2</sup> and excluded observations above the 99th percentile of relative loss. All relationships were interpreted as spatial associations rather than causal effects.

**3. RESULTS****3.1 Global Forest Landscape Structure and Composition**

The FOS/FAD analysis showed substantial geographical variation in forest landscape structure across the 2020 baseline. The five forest classes Rare, Patchy, Transitional, Dominant, and Interior represented a gradient from fragmented to increasingly continuous forest configurations. Of the total analytical area of 603,669,088.38 km<sup>2</sup>, the Non-Forest/Background category accounted for 94.71%, while the five forest landscape-structure classes collectively represented 5.29%. Dominant was the largest forest class (2.09%), followed by Interior (1.92%), Transitional (0.70%), Patchy (0.52%), and Rare (0.06%). The geographical distribution of these forest landscape-structure classes is shown in Figure 1.



**Figure 1. Global Forest Landscape Structure Based on FOS/FAD Classification, 2020.**

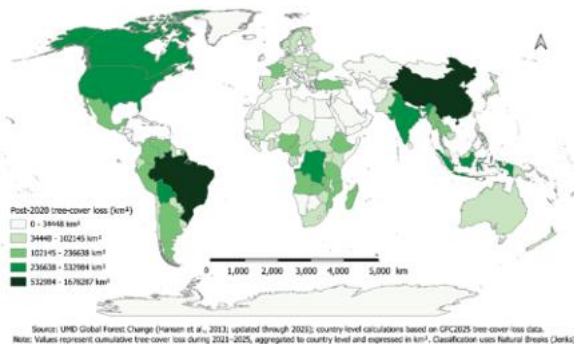
GFT2020 identified 61,157,768.51 km<sup>2</sup> of mapped forest. As shown in Table 1, naturally regenerating forest accounted for 56.17%, primary forest for 36.96%, and planted/plantation forest for 6.86%. Forest-type composition varied substantially among geographical units. Among the ten units with the largest mapped forest areas, primary forest was dominant in the Russian Federation (67.38%), Canada (63.42%), and Colombia (52.19%), whereas naturally regenerating forest was dominant in the other seven units.

**Table 1. Global Forest Composition by Forest Type, GFT2020.**

| Forest type                   | Area (km <sup>2</sup> ) | Percentage (%) |
|-------------------------------|-------------------------|----------------|
| Naturally regenerating forest | 34,354,940.04           | 56.17          |
| Planted/plantation forest     | 4,196,800.02            | 6.86           |
| Primary forest                | 22,606,028.45           | 36.96          |
| Total mapped forest           | 61,157,768.51           | 100.00         |

### 3.2 Post-2020 Tree-Cover Loss

Cumulative detected tree-cover loss during 2021–2025 varied substantially among the 276 geographical units. The highest absolute losses were recorded in Brazil (1,678,286.53 km<sup>2</sup>), the Russian Federation (1,632,351.26 km<sup>2</sup>), and China (1,554,759.64 km<sup>2</sup>). Other geographical units among the ten highest included the Democratic Republic of the Congo, India, the United States, Indonesia, Canada, Bolivia, and Angola. The geographical distribution of cumulative detected tree-cover loss during 2021–2025 is shown in Figure 2.



**Figure 2. Global Geographical Distribution of Cumulative Detected Tree-cover Loss During 2021–2025.**

The geographical pattern changed when loss was expressed relative to baseline forest area. Among these ten units, India recorded the highest relative loss (52.34%), followed by China (49.69%), Bolivia (36.21%), Angola (26.85%), and the Democratic Republic of the Congo (26.82%). Across all 276 geographical units, cumulative detected loss totalled 13,241,876.21 km<sup>2</sup>, with a mean of 47,977.81 km<sup>2</sup> and a median of 2,719.58 km<sup>2</sup>. Sixty-seven geographical units recorded zero detected loss during the study period.

### 3.3 Associations Between Baseline Forest Characteristics and Detected Loss

Cumulative detected loss showed a very strong positive association with total forest area (Spearman's  $\rho = 0.954$ ,  $p < 0.001$ ;  $n = 276$ ). Naturally regenerating forest percentage showed a weak negative association ( $\rho = -0.227$ ), while planted/plantation and primary forest percentages showed positive associations ( $\rho = 0.607$  and  $0.686$ ,

respectively). For relative loss, total forest area showed a weak positive association ( $\rho = 0.226$ ), naturally regenerating forest percentage showed a weak negative association ( $\rho = -0.223$ ), planted/plantation forest showed a positive association ( $\rho = 0.390$ ), and primary forest showed no statistically significant association ( $\rho = 0.023$ ,  $p = 0.715$ ).

The full multivariate model explained 88.3% ( $R^2 = 0.883$ ) of the variation in log-transformed absolute loss. Total forest area had a positive coefficient (+1.044), while naturally regenerating and primary forest percentages had negative coefficients ( $-0.0226$  and  $-0.0228$ , respectively;  $p < 0.001$ ). The corresponding relative-loss model explained 14.6% ( $R^2 = 0.146$ ) of the variation. The directions of the coefficients remained stable in the sensitivity analyses, although explanatory power differed among model specifications.

## 4. DISCUSSION

The results demonstrate that forest extent alone provides an incomplete geographical representation of global forest landscapes. The FOS/FAD classification revealed substantial variation in spatial configuration, ranging from Rare and Patchy to Dominant and Interior Forest classes. This indicates that geographical units with forest cover may differ considerably in the degree of fragmentation and continuity. However, these classes describe spatial configuration and should not be interpreted directly as measures of biodiversity, habitat quality, or ecological condition.

The GFT2020 results further demonstrate that global forest resources differ in composition. Naturally regenerating forest represented the largest component of mapped forest, followed by primary and planted/plantation forest. The geographical variation in these components indicates that forest area does not adequately describe the characteristics of the forest resource. As shown by the combined spatial and compositional assessment, forest landscapes therefore require more than a single measure of extent.

The analysis of detected tree-cover loss during 2021–2025 revealed strong geographical differences in both absolute and relative loss. The very strong association between total forest area and cumulative loss ( $\rho = 0.954$ ) indicates that geographical units with larger baseline forest areas contributed substantially to the magnitude of detected loss. However, the weaker association between forest area and relative loss ( $\rho = 0.226$ ) demonstrates that absolute loss and proportional loss represent different geographical dimensions of forest disturbance.

The multivariate results reinforce this distinction. The absolute-loss model explained substantially more variation ( $R^2 = 0.883$ ) than the relative-loss model ( $R^2 = 0.146$ ), suggesting that baseline forest extent accounts for much of the geographical variation in loss magnitude, whereas proportional loss reflects additional factors not included in the models. These relationships are spatial associations rather than causal effects.

Overall, integrating forest structure, composition, and recent detected tree-cover loss provides a more comprehensive geographical framework for global forest monitoring.

## 5. CONCLUSION

This study provides an integrated global geographical assessment of forest landscape structure, forest composition, and detected tree-cover loss during 2021–2025 across 276 geographical units. The results demonstrate that forest extent alone does not adequately represent the spatial characteristics of forest landscapes. The FOS/FAD analysis identified substantial variation in forest configuration, while GFT2020 revealed marked differences in the proportions of naturally regenerating, primary, and planted/plantation forests.

The analysis of post-2020 detected tree-cover loss further showed strong geographical variation in both absolute and relative loss. The strong association between baseline forest area and cumulative loss, together with the substantially lower explanatory power of the relative-loss model, highlights the importance of distinguishing forest extent from proportional disturbance. The findings also demonstrate the value of combining spatial structure, forest composition, and recent tree-cover loss rather than relying on a single forest indicator.

Overall, the framework provides a reproducible geographical approach for integrating multiple global Earth-observation datasets to characterize forest landscapes and their recent disturbance patterns.

The results can support geographically differentiated forest monitoring and provide a basis for further investigation of the environmental and socioeconomic factors underlying observed spatial differences in forest loss.

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