Estimation of Forest Structural Parameter using Remote Sensing Technology in Central Mindanao University

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ABSTRACT

Effective monitoring of natural forest ecosystems requires efficient and scalable approaches to address the limitations of conventional field-based measurements, which are often labor-intensive, costly, and spatially constrained. This study explores the application of Sentinel-2 multispectral imagery for assessing forest structural parameters in the natural forest of Central Mindanao University (CMU), Bukidnon, Philippines. Field data on crown length, tree frequency, and basal area were collected from fifteen sample plots and compared with remote sensing–derived vegetation indices, including the Normalized Burn Ratio (NBR), Moisture Vegetation Index (MVI), and Sentinel-2 Band 2 reflectance. Statistical analyses revealed a strong correlation between crown length and the combined indices of NBR, MVI, and Band 2 reflectance, with an adjusted R^2 of 0.885, highlighting their capability to capture canopy moisture status, disturbance intensity, and understory conditions. In contrast, tree frequency showed a moderate relationship with maximum NBR values (adjusted $R^2 = 0.339$), suggesting that individual indices have limited explanatory power for certain structural attributes. Spatial analysis further demonstrated that undisturbed forest core areas exhibit longer crown lengths, while fragmented and peripheral zones are characterized by shorter crowns, reflecting the impacts of human activities and subsequent forest regeneration. Overall, the results indicate that Sentinel-2 imagery provides a cost-effective and scalable framework for forest condition assessment, supporting adaptive forest management, conservation of mature forest patches, and informed planning for reforestation and assisted natural regeneration in disturbed areas.

Keywords: CMU, Natural Forest Monitoring, Remote Sensing, Sentinel-2, Vegetation Indices

INTRODUCTION

Concern over the status and use of the world's natural forests has grown significantly during the past years. Forests serve vital ecological and economic purposes. Not only do trees supply goods and livelihoods but they help preserve soils, control water flow and retain carbon that may otherwise add to greenhouse emissions. As the world's population increases, so will the demand for forest products. Natural forest areas play a vital role in maintaining ecological balance, preserving biodiversity, and supporting long-term forest conservation. Unlike industrial tree plantations (ITPs), which are designed for commercial timber production, natural forests provide a broader range of ecosystem services, including carbon storage, water regulation, and habitat protection. While ITPs currently supply around 33% of global wood demand and help alleviate logging pressure on natural forests (Bruinsma, 2002), the conservation and sustainable management of natural forest areas remain essential. In the Philippines, particularly in regions like Mindanao, natural forests underpin local agroforestry systems and contribute significantly to community livelihoods and environmental resilience (DOST-PCAARRD, 2018). However, traditional inventory methods for monitoring plantation health and productivity such as manual field surveys remain labor-intensive, costly, and spatially limited (Olpenda et al., 2023). Remote sensing (RS) technology offers a transformative alternative by enabling large-scale, cost-effective assessments of vegetation parameters such as biomass, canopy structure, and growth trends (Nguyen et al., 2020; Brown et al., 2022). Sentinel-2 multispectral imagery, with its high temporal resolution and red-edge bands, has proven particularly effective for mapping forest attributes like basal area and stem volume (Marcelli et al., 2020; Frampton et al., 2013). At Central Mindanao University (CMU) in Musuan, Maramag Bukidnon, forest areas are vital income-generating assets, yet their management lacks updated geospatial tools to optimize harvesting and monitor sustainability (CMU CLUP, 2016). Existing studies at CMU have focused on biodiversity and silviculture (Tulod et al., 2017; Rojo & Paquit, 2018), but RS applications remain underexplored. This gap hampers the university's capacity to determine harvesting locations, manage plantations adaptively, and plan operations using climate resilient techniques. Building on previous studies by Olpenda et al. (2023), this study suggests using Sentinel-2 data to fill this gap and establish a replicable framework for spatially explicit forest management.

METHODOLOGY

Locale of the Study

The study was conducted in a selected forest patch of Central Mindanao University as shown in figure 1 with a latitude of 7.859 and longitude of 125.0471. Fifteen (15) sites were preselected with a minimum distance of 40 meters each site.

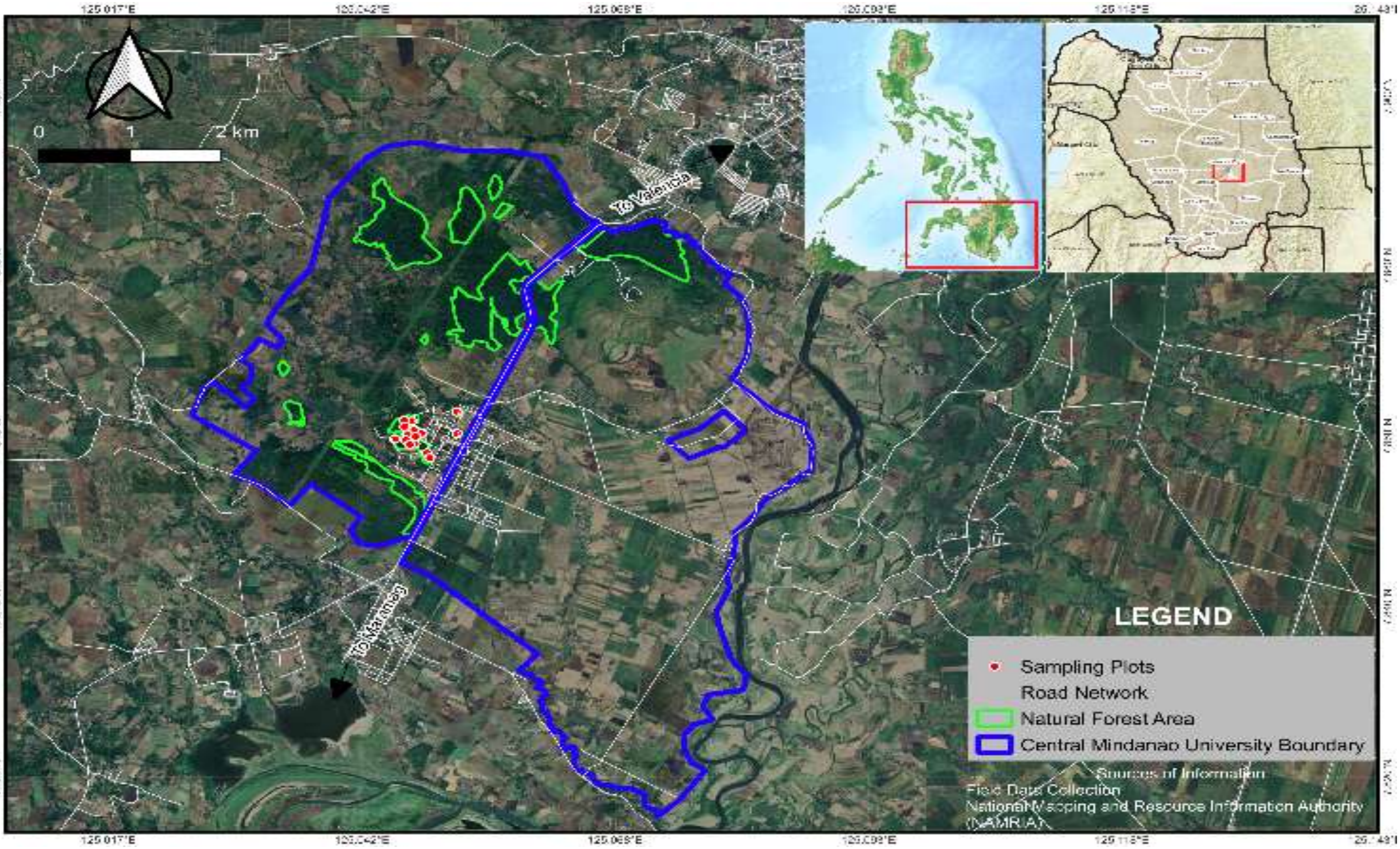

Figure 1. Locale of study

Data Gathering

Downloading of Satellite Images and Indices

The satellite imagery used in this study is Sentinel-2, acquired from the Copernicus website. It has a spatial resolution of 10 meters and a cloud cover of no more than 15%, covering the period from April to May 2025. Using various Sentinel-2 spectral bands, several vegetation indices were calculated in QGIS software.

Field Data Collection

Preselected plots were delineated in QGIS using a 23-meter radius and a minimum spacing of 40 meters to prevent overlap. Field data collected from these plots included diameter at breast height (DBH), total height, crown width, crown length, volume, and basal area. Additionally, species identification and understory vegetation data were recorded.

Data Analysis

Band indices were processed using QGIS software, while statistical analyses of the field data were conducted in SPSS. Correlation and regression analyses were performed in SPSS to examine the relationships between the spectral bands, vegetation indices, and field measurements.

RESULTS AND DISCUSSION

Of the six dependent variables analyzed, only two showed a statistically significant correlation in the regression analysis namely crown length and frequency or the number of trees.

Mean Crown Length (CL)

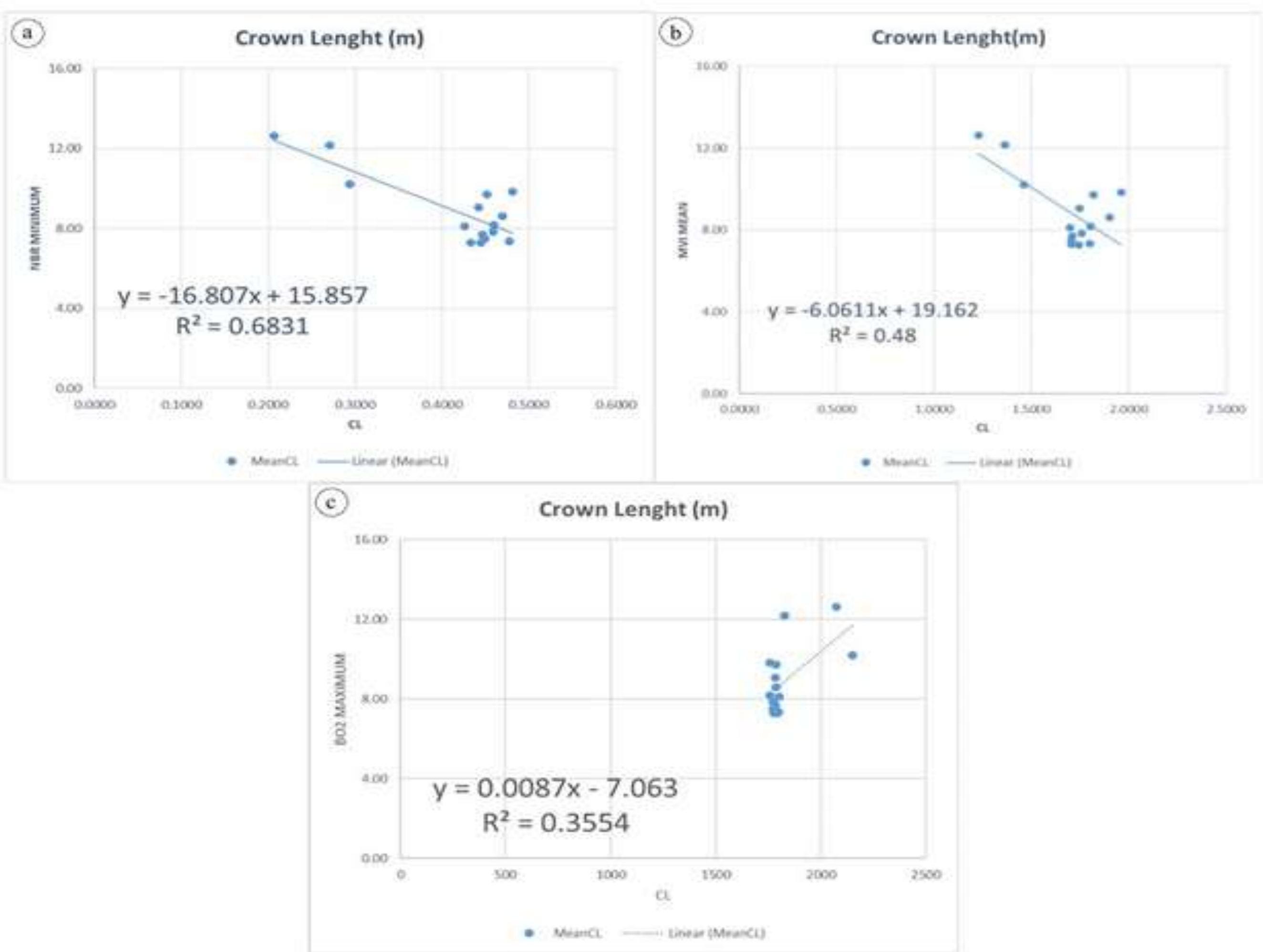

Figure 2. Relationship between Crown Length and Selected Remote Sensing-Derived Variables in Natural Forest Areas of Central Mindanao University, (a) NBR Minimum vs. Crown Length, (b) MVI Mean vs. Crown Length, (c) Band 2 Maximum Reflectance vs. Crown Length)

MVI Mean (Moisture Vegetation Index) has a strong positive coefficient (+16.23), indicating that higher moisture availability correlates with longer crowns. Moisture-rich soils enhance nutrient uptake and photosynthetic efficiency, promoting lateral crown expansion. This aligns with studies showing that water availability directly impacts canopy development in tropical plantations (Zhu et al., 2014). NBR has a significant negative coefficient (−60.21), meaning areas with higher NBR (less disturbed, healthier vegetation) exhibit shorter crowns. High NBR values signify dense, undisturbed stands where competition for light and resources limits lateral crown growth. Trees prioritize vertical growth over crown spread, reducing crown length (Tulod et al., 2017). BO2 Max (Sentinel-2 Band 2, 490 nm blue band) has a slight negative coefficient (−0.006), suggesting that higher blue-band reflectance correlates with shorter crowns. The blue band is sensitive to soil and understory reflectance. In sparse canopies, exposed soil or understory vegetation increases blue-band reflectance, indirectly signaling lower crown density (Huete, 1988). The integration of multiple indices (MVI, NBR, BO2) improves canopy cover prediction by moisture dynamics (MVI), disturbance/competition (NBR), soil/understory interference (BO2). Hybrid models using red-edge and SWIR bands (e.g., NBR) with visible bands (e.g., BO2) mitigate spectral limitations, enhancing accuracy in heterogeneous tropical stands (Frampton et al., 2013).

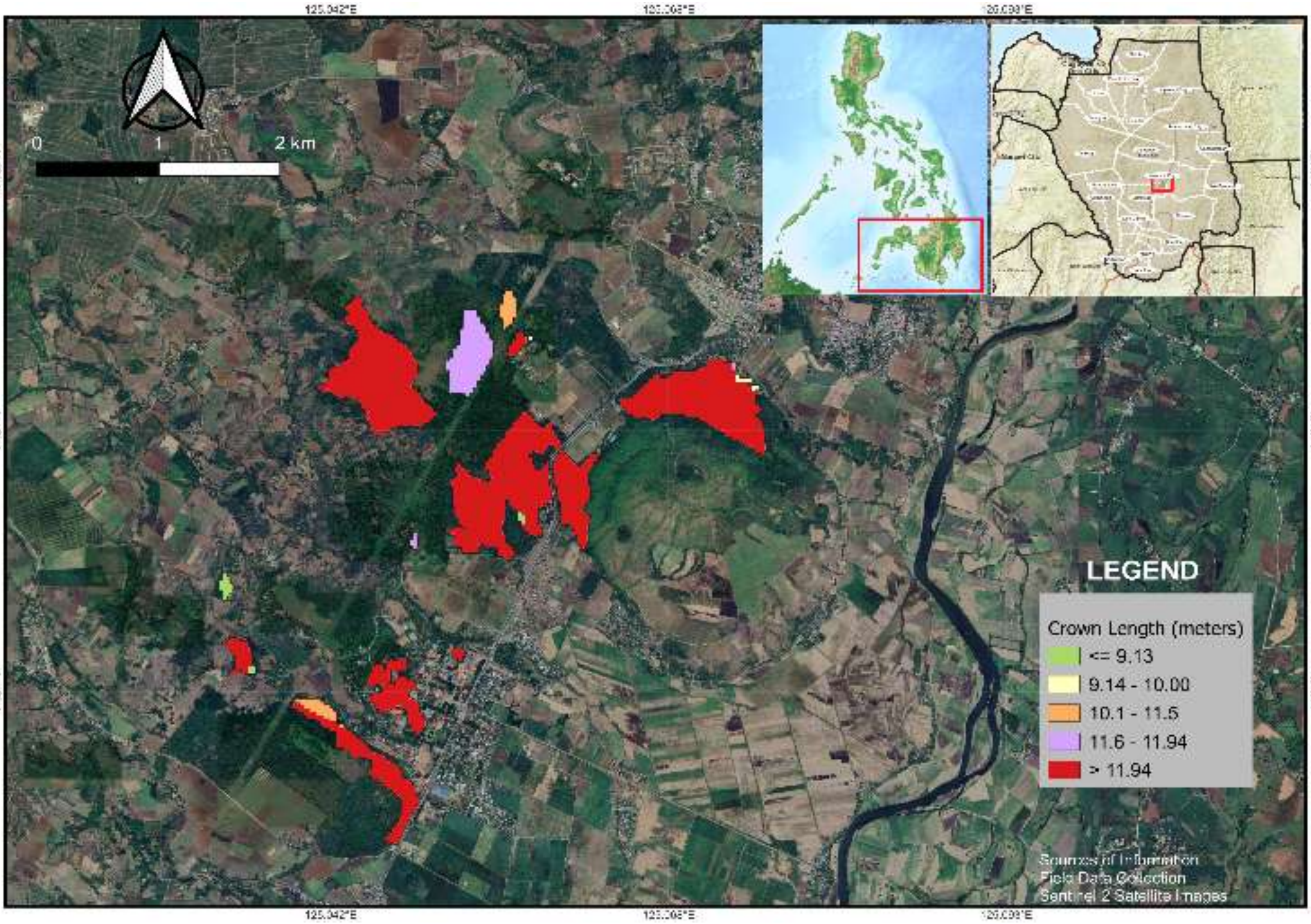

Figure 3. Crown Length Distribution in the Natural Forest of Central Mindanao University Derived from Sentinel-2 Imagery.

Crown length serves as a key indicator of forest health and age, as it often correlates with the height and vigor of trees. In figure 3, longer crown lengths exceeding 11.94 meters (represented 6 in red) are commonly associated with mature, well-established trees growing in healthy and undisturbed forest areas. In contrast, shorter crown lengths, indicated by green to orange colors, suggest the presence of younger or regenerating forests, disturbed or secondary forests, or areas dominated by species with naturally smaller crowns. The spatial distribution of crown lengths further reveals the structure and condition of the forest landscape. Areas with long crown lengths are primarily located in the central-western and southwestern zones. These regions are likely core zones of natural or old-growth forest, characterized by minimal disturbance, ecological stability, and favorable environmental conditions such as rich soils and sufficient moisture. On the other hand, smaller crown lengths are scattered in peripheral or fragmented parts of the area. These patches could represent edge habitats, recovering or degraded zones due to previous logging or agriculture, or forest stands influenced by environmental stressors and species variation. Forest fragmentation is evident in the landscape, with crown length patches embedded within a matrix of agricultural lands and settlements. This fragmentation can compromise forest connectivity, leading to isolated patches that are susceptible to reduced biodiversity, limited wildlife movement, and increased edge effects like wind exposure, temperature extremes, and encroachment by invasive species. This result also highlights the significant anthropogenic impact on the forest, as evident from surrounding agricultural activity and nearby urban settlements. The proximity of major forest patches to roads and towns suggests increased human pressure, including land conversion, logging, and development. This underscores the importance of monitoring and implementing conservation measures to mitigate degradation and support forest sustainability.

Number of trees (Frequency)

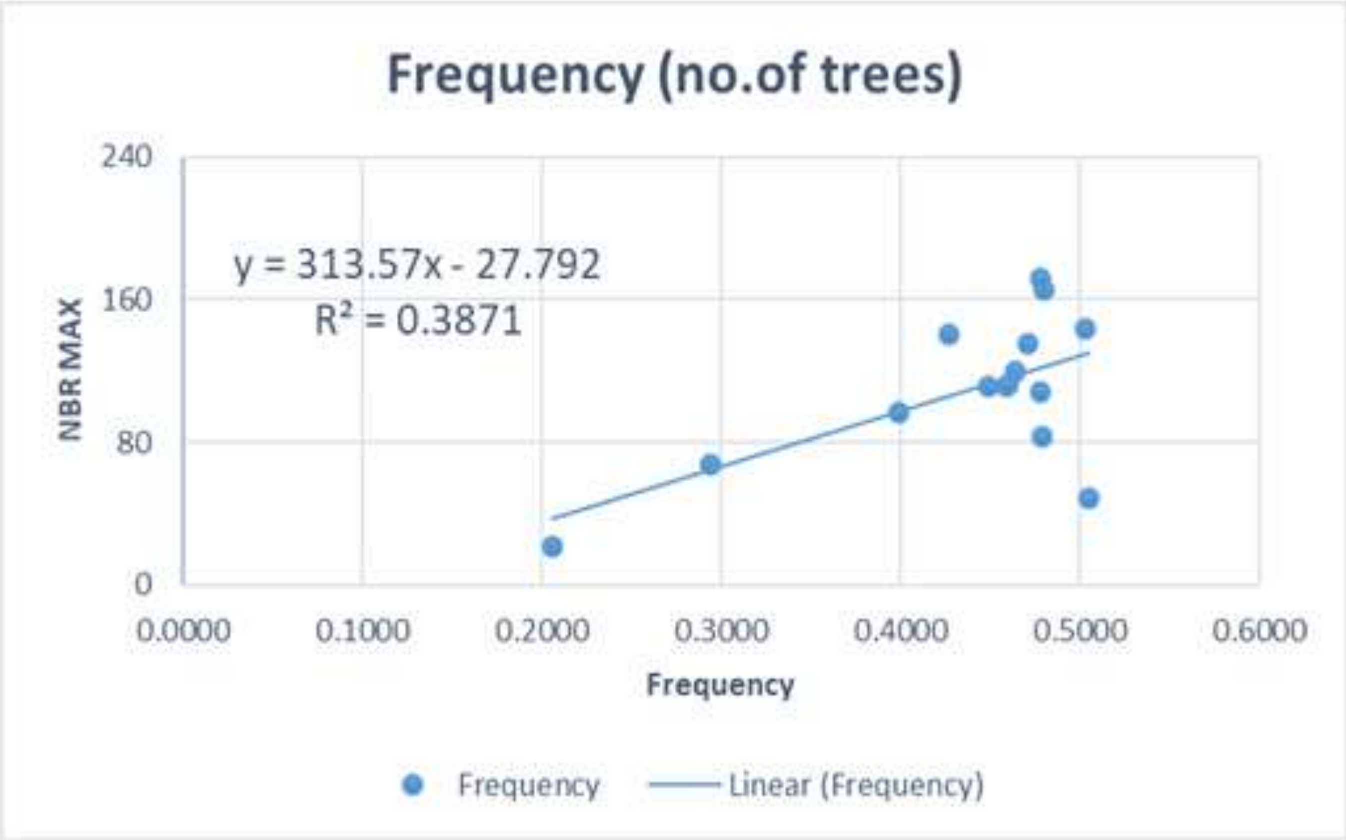

Figure 4. Relationship between Tree Frequency and Maximum NBR Values in Natural Forest Areas of Central Mindanao University

NBR has an exceptionally strong positive coefficient (+313.57), implying that higher NBR values (indication of healthy, unburned vegetation) correlate with increased frequency of measurable growth or stress events. Although NBR is a strong predictor, other factors (such as soil quality and microclimate) also affect event frequency, as seen by the fact that it accounts for 38.7% of the variance in frequency. The R2=0.339 value accounts for model complexity, confirming that NBR alone has limited but meaningful predictive capacity. The high standard error of 33.60 reflects substantial variability unaccounted for by NBR, likely due to omitted variables (e.g., species diversity, management practices). In contrast to the crown length (CL) models, which had more explanatory power (R2= 0.556 and R2=0.910, respectively) because of the stronger correlation between ARVI and biomass/chlorophyll (Frampton et al., 2013) and hybrid indices (MVI, NBR, BO2) that capture moisture and competition dynamics (Zhu et al., 2014) the frequency model's lower R2=0.387 illustrates how NBR places more emphasis on vegetation health than structural characteristics. Nevertheless, NBR is still essential for practical applications: its capacity to identify stressed areas (low NBR) allows for focused pest and drought control measures (DOST-PCAARRD, 2018), while high NBR regions, which represent healthy stands, use growth tracking to maximize harvest timings. This emphasizes how NBR functions as a complementary instrument that strikes a balance between operational effectiveness and ecological monitoring.

The correlation analyses further demonstrate the utility of Sentinel-2 imagery in forest assessment. Despite its moderate spatial resolution (10–20 m), the sensor’s high temporal frequency and spectral richness allow for practical, consistent monitoring of forest conditions. These indices, when calibrated against field data, provide valuable insights into forest structural variability (Frampton et al., 2013; Fassnacht et al., 2016). For operational use, CMU’s Forest managers are encouraged to integrate these remote sensing based indicators into plantation management workflows. For example, annual NDVI or NBR composites can help monitor vegetation vigor and detect early signs of canopy stress. GIS based change detection methods may also assist in identifying logging disturbances or areas of regeneration. Incorporating these tools can enhance ongoing plantation assessments and enable adaptive responses as forest conditions change (Lu et al., 2016; DOST-PCAARRD, 2018).

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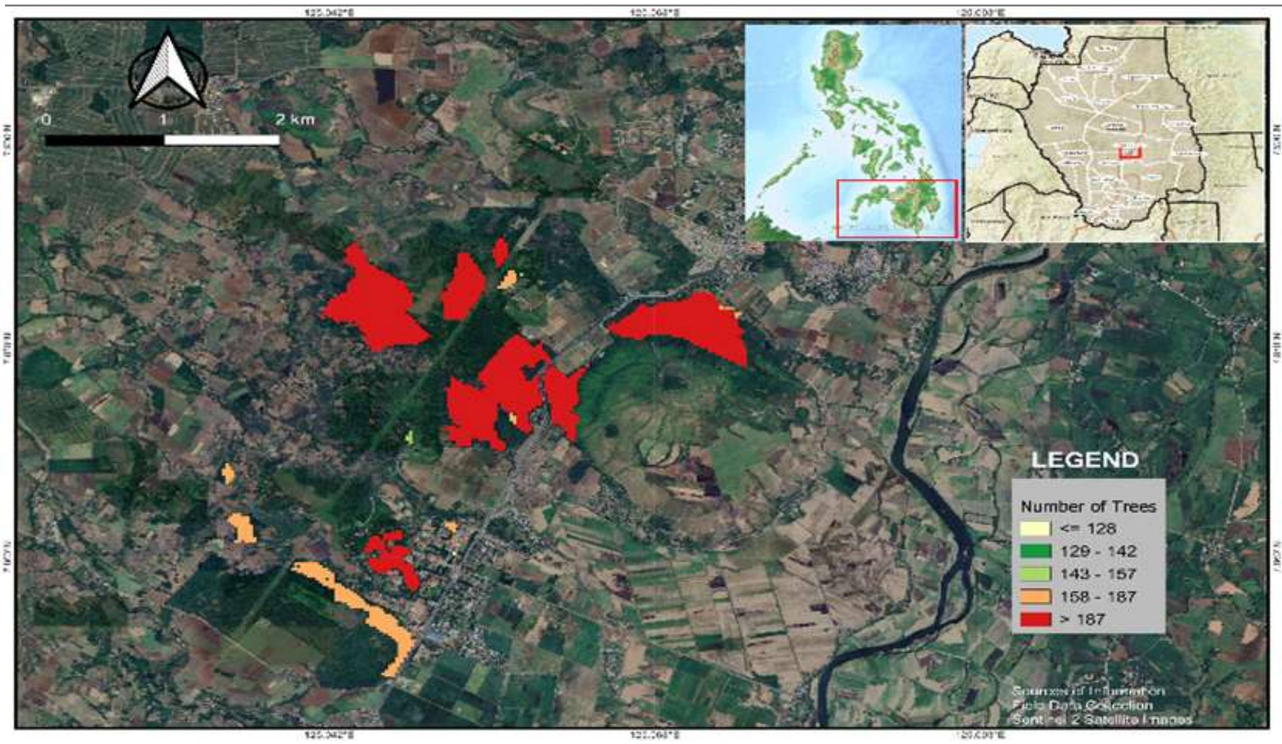

Figure 5. Tree Frequency Distribution in the Natural Forest of Central Mindanao University Based on Remote Sensing-Derived Estimates

Figure 5 shows the spatial pattern of tree density across the forest landscape of Central Mindanao University, generated using Sentinel-2 imagery supported by field validation. Areas marked in red polygons, particularly in the central and northeastern portions, indicate tree densities exceeding 187, corresponding to well-established stands with mature trees and dense canopy cover. In contrast, lighter shades (e.g., yellow to light green) appear mostly in the southern and peripheral zones and may reflect younger growth, past logging activity, or natural regeneration. This spatial pattern illustrates the effectiveness of remote sensing in detecting structural variation across forest stands. While these observations align with prior analyses of NBR derived frequency estimates, the map adds geographic context useful for prioritizing site-level interventions. Integrating such visualizations into forest planning supports data-informed decisions on restoration, biodiversity conservation, and yield monitoring (Lu et al., 2016; DOST-PCAARRD, 2018).

CONCLUSIONS AND IMPLICATIONS

As anticipated, the strength of the correlation varies with the number of sampling plots. While a minimum of 30 plots is typically recommended for statistical effectiveness, constraints in area and time limited our study to only fifteen (15) plots with 2000 sampling trees. While the observed relationships between Sentinel-2 derived indices and selected forest structural parameters are statistically meaningful, they are best framed as exploratory rather than fully predictive. Small sample sizes may increase uncertainty and the risk of overfitting, particularly in multivariate regression models. Nonetheless, the consistency of the relationships especially between crown length and the combined indices of NBR, MVI, and Band 2 reflectance suggests that these spectral variables capture ecologically relevant signals related to canopy moisture, disturbance gradients, and understory exposure. The strong performance of NBR in relation to crown structure can be theoretically explained by its sensitivity to canopy condition and internal forest disturbance. Although NBR is traditionally associated with burn severity, its formulation using near-infrared (NIR) and shortwave infrared (SWIR) bands makes it responsive to changes in canopy density, crown continuity, and moisture stress. In dense, undisturbed stands, high NBR values may reflect vertically oriented crowns shaped by intense competition for light, whereas lower NBR values can indicate more open or heterogeneous canopy structures associated with lateral crown expansion. This interpretation is supported by prior studies highlighting the utility of SWIR-based indices in capturing forest structural complexity and canopy integrity.

To support sustainable operational planning at Central Mindanao University, plantation managers are encouraged to integrate remote sensing-derived insights into their forest assessment and decision-making processes. The findings confirm the practical value of Sentinel-2 imagery in estimating important forest structural parameters, even with limited field data. Specifically, spectral indices such as NBR, MVI, and Band 2 reflectance should be used to monitor forest conditions. The strong statistical relationship between crown length and these indices, particularly those related to red-edge, NIR, and blue bands, demonstrates their usefulness in identifying canopy moisture, disturbance levels, and understory visibility. Longer crowns, associated with high MVI and low NBR values, can help locate mature and ecologically valuable forest areas for protection. In contrast, shorter crowns and lower spectral responses may indicate damaged or recovering areas that require reforestation or assisted regeneration. While the number of trees showed only a moderate correlation with NBR, its spatial variation across the forest can still serve as a helpful guide for identifying areas undergoing regeneration or for planning selective harvests. These relationships can be operationalized by incorporating them into regular monitoring routines, identifying management priorities, and informing harvest schedules. By adopting these remote sensing-based tools and methods, CMU's plantation managers can implement more informed, adaptive, and cost-effective strategies that support long-term forest conservation, enhance ecological health, and improve overall productivity.

RECOMMENDATION

This study recommends the integration of Sentinel-2 remote sensing data and vegetation indices such as NBR, MVI, and Band 2 reflectance into regular forest monitoring activities at Central Mindanao University. These indicators provide a cost-effective means of assessing canopy condition, identifying mature forest stands for conservation, and detecting disturbed or regenerating areas for targeted restoration. Forest zones with longer crown lengths should be prioritized for protection, while areas with shorter crowns may be designated for reforestation or assisted natural regeneration. Although tree frequency exhibited only a moderate relationship with NBR, the index remains useful for identifying forest stress and disturbance patterns. Future research should increase the number of field plots and explore higher-resolution datasets or advanced analytical methods to further improve the accuracy of forest structural parameter estimation and support adaptive, sustainable forest management.

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