Structural Parameter Estimation in a Complex Mixed Conifer-Broadleaf Forest: Insights from UAV RGB Imagery through Structural, Textural, and Spectral Metrics

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Introduction/Aim:

Forest structure is the three-dimensional arrangement of its components, plays a crucial role in understanding forest ecological functions. Quantitative assessments of forest structure rely on forest structural parameters that capture various aspects of this arrangement. While estimating these parameters is relatively accurate in even-aged and simply structured forests, it remains challenging in complex mixed forests. Simply structured forests can often be accurately predicted with a smaller set of remote sensing metrics. However, the complexity of mixed forests demands a broader range of variables due to their dependence on multiple factors. In this study, we utilized UAV RGB imagery and an area-based approach to estimate several key structural parameters: Our objective was to identify suitable structural, textural, and spectral UAV metrics as explanatory variables for predicting forest structural parameters with high accuracy.

Methods:

We utilized the DJI Matrice 300 RTK UAV equipped with a Zenmuse P1 RGB sensor to capture imagery within mixed conifer-broadleaf forest compartments (com16 and com65-66) at the University of Tokyo Hokkaido Forest, Japan. Using structure from motion (SfM) technology and Pix4Dmapper photogrammetry software, dense point clouds were generated. Digital surface models (DSMs) and orthomosaics were derived from these point clouds, while canopy height models (CHMs) were created using DSMs and existing airborne LiDAR digital terrain models (DTMs). Structural and textural metrics were extracted from CHMs, and spectral metrics were derived from orthomosaics and these metrics were used to esimate dominant tree height (Hd), tree diameter at breast height (DBH), basal area (BA), stand volume (V), carbon stock (CST), stem density (Sden), and broadleaf ratio (BLr). We employed multiple linear regression (MLR) and random forest (RF) regression models, selecting UAV metrics through stepwise variable selection for MLR and ranking important UAV metrics by the percent increase in mean squared error for RF. Model accuracy was assessed via leave-one-out cross-validation against field data.

Results:

We found that a relatively high estimation accuracy was obtained for all forest structural parameters with the inclusion of structural, textural, and spectral metrics using both RF and MLR. Comparatively, the RF performed well to predict the field forest structural parameters. The models selected suitable UAV metrics as many as to predict the respective field forest structural parameters for obtaining high estimation accuracy. We obtained the estimation accuracy for Hd (R^2 = 0.86–0.93, RMSE = 0.61–1.02), DBH (R^2 = 0.45–0.89, RMSE = 0.96–2.24), BA (R^2 = 0.54–0.98, RMSE = 0.63–3.49), V (R^2 = 0.53–0.90, RMSE = 18.43–42.60), Sden (R^2 = 0.64–0.86, RMSE = 13.46–44.88) and BLr (R^2 = 0.54–0.87, RMSE = 0.03-0.56) using RF and MLR.

Conclusion:

The inclusion of textural and spectral metrics together with structural metrics was shown to be the best choice to predict the forest structural parameters in a complex forest, as its structure depends on many factors. The number of variables selected by the models differed depending on the field forest structural parameters. Comparatively, the performance of the RF model was excellent for all field forest structural parameters across the study area. Our reliable results will support foresters predicting forest structural parameters using UAV photogrammetry and thus contribute to sustainable forest management.