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Mapping Forest Stand Characteristics Using Aerial LiDAR and Sentinel-1 Data: A Case Study from Slovenia

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Advancements in remote sensing technologies have enabled comprehensive and detailed forest mapping, as demonstrated by recent initiatives in Slovenia. Such maps are essential for sustainable forest management, biodiversity conservation, and monitoring changes in forest structure and composition over time. A forest stand map was generated for the year 2023 in central Slovenia, encompassing 7,005 km², 62% of which is forested. We developed and calibrated two distinct models based on Sentinel-1 SAR data to map growing stock and the proportion of coniferous and broadleaved species in growing stock. In addition, we used the LiDAR-based canopy height model (CHM) to map forest stand height and canopy cover.

LiDAR data acquisition occurred in spring 2023, coinciding with varying levels of leaf development across deciduous forests. This led to heterogeneity in the point cloud data, affecting CHM-based estimations of forest stand height and canopy cover. Tree-top CHM heights were relatively unaffected, but the crown shapes of deciduous trees were heavily influenced by the state of leaf development. To mitigate these effects, the CHM's horizontal resolution was reduced by aggregating the highest point within each 10-meter pixel, downsampled from the original 50 cm CHM. Forest stand height was calculated as the mean height of all 10-meter CHM pixels within forest stand polygons. Canopy cover was derived as the percentage of 10-meter pixels exceeding a height threshold of 20 meters.

Growing stock and the proportion of species were estimated using random forest models trained on field-measured forest stand data, and Sentinel-1 imagery. Field data were provided by the Slovenian Forestry Service and included forest stand data for quasi-randomly distributed forest management units. Vegetation indices were derived from Sentinel-1 daily data, including the Radar Vegetation Index (RVI = 4 × VV / (VV + VH)), the Normalized Radar Vegetation Index (NRVI = (VV - VH) / (VV + VH)), and the Radar Forest Degradation Index (RFDI = VV - VH), where VV and VH represent Sentinel-1 polarization modes. Monthly composites of these indices, spanning January 2022 to December 2023, were generated and smoothed using a 3 × 3 low-pass filter.

The random forest models, consisting of 100 regression trees each, were optimized based on R^2 performance on unseen test data generated during the cross-validation process. The optimal tree depths were 20 and 15 for the growing stock and the proportion of species models, respectively, yielding R^2 values of 0.34 and 0.57. Final model-based predictions were aggregated to forest stand polygons, providing spatially explicit estimates of growing stock and species composition.

Forest stands were delineated using the Segment Mean Shift image segmentation tool in ESRI ArcGIS Pro, applied to a set of Z-score standardized raster maps representing forest stand height, canopy cover, and the proportion of coniferous and broadleaved species. Further work is planned to include lidar data and optical data into the models.

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