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| **Modelling Annual Basal area increment of Scots Pine stands using Tree-ring Observations and Multisource Remote Sensing Data** |
| Accurate assessment of basal area increment (BAI) is fundamental to understanding forest growth dynamics. Annual BAI allows for the interpretation of growth trends and provides a direct measure of wood production. Most studies on BAI rely on data from permanent sample plots, where measurements are taken every few years. The other main source of data for BAI analysis is tree-ring data, but due to the high costs, tree cores are usually only available for a few trees per sample plot. Our study presents an integrated approach to modelling annual BAI utilising data from multiple sources, including an unprecedentedly comprehensive tree-ring dataset, airborne laser scanning (ALS) point clouds, Sentinel-2 and MODIS satellite imagery, and selected climatic variables derived from the TerraClimate dataset.  The study was carried out in Scots pine stands located in Poland. The 300 plots were distributed throughout the country with stratification in age and site condition classes. The tree-ring cores provided reference data for BAI, capturing growth patterns with annual temporal resolution. The field campaign was carried out in 2022. At each plot, the tree-ring cores were collected from all trees on the plot (minimum 30 trees per plot), giving more than 9,000 tree-ring core samples. Standard tree characteristics, including diameter at breast height and tree height were measured. The coordinates of the plot centres were collected with a high-precision GNNS receiver providing submeter accuracy. The BAI was calculated based on tree rings for the period 2017-2021.  The Generalised Additive Models (GAM) approach was used to model the relationships between tree-ring-derived annual BAI and the integrated suite of explanatory variables derived from remote sensing data, including: metrics derived from ALS point clouds (e.g. mean height of tree tops, stand density from tree tops, leaf area density), mean monthly values of number of vegetation indices (VIs) calculated from all available Sentinel-2 cloud-free imageries (e.g. NDVI, NDRE, NDWI, PPI), selected MODIS products (e.g. annual NPP, monthly PAR) and several climatic variables derived from TerraClimate dataset (e.g. precipitation, temperature, vapour pressure deficit). Thanks to using GAM approach, it was possible to develop complex model including interannual variability of VIs and climatic variables keeping the model interpretable.  The results obtained demonstrate the efficacy of the proposed approach in accurately predicting annual BAI. Remote sensing-derived variables substantially improved the accuracy of BAI compared to the model based solely on standard stand characteristics derived from traditional field measurements. The model developed based on data from 240 training plots including BAI observations from 2017-2020 and validated on observations from 2021 on 60 test plots, provided high accuracy: R2 = 0.78, RMSE% = 30.1% and MAE% = 22.1%.  By combining the comprehensive tree-ring dataset with ALS and satellite observations, and using the interpretable GAM method, the performed study provides a thorough understanding of the BAI of Scots pine stands, providing valuable insights for applications of remote sensing data in forest monitoring and sustainable forest management. |