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Editorial

Multi-Scale Remote Sensing-Assisted Forest Inventory: A Glimpse of the State-of-the-Art and Future Prospects

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Abstract: Advances in remote inventory and analysis of forest resources during the last decade have reached a level to be now considered as a crucial complement, if not a surrogate, to the long-existing field-based methods. This is mostly reflected in not only the use of multiple-band new active and passive remote sensing data for forest inventory, but also in the methodic and algorithmic developments and/or adoptions that aim at maximizing the predictive or calibration performances, thereby minimizing both random and systematic errors, in particular for multi-scale spatial domains. With this in mind, this editorial note wraps up the recently-published *Remote Sensing* special issue "Remote Sensing-Based Forest Inventories from Landscape to Global Scale", which hosted a set of state-of-the-art experiments on remotely sensed inventory of forest resources conducted by a number of prominent researchers worldwide.

Keywords: remote sensing; forest resources inventory; spatial scale

1. Introduction

Forest inventory practices, in particular on the classical basis of design-based surveys, have been long considered as essential sources of quantitative and qualitative information for current forest resources management. In addition, they are also deliberated as essential inputs to future projections of forest status, health and services [1]. As previously stated by [2], scheming and implementation of any future strategy for forest management is essentially based on postulating the availability of accurate and unbiased estimations on basic forest inventory attributes on multiple spatial scales ranging from single tree to forest stand, i.e., common management unit, and even to larger domains of landscape, statewide or country-wide levels. Whereas the majority of field-based means of inventory are considered as complex (in design, localization and measurement), not standardized between countries and spatiotemporally constrained, satellite and airborne remote sensing are geo-located, cost-effective and temporally continuous, thereby enabling spatially explicit and even automatic estimation and mapping of various forest inventory attributes [3].

The application of remote sensing data and techniques in forest inventory dates back to the early days of aerial photography for civil applications and has experienced a substantially rapid advancement since the development of active sensors, such as LiDAR and the launch of satellite earth observation programs. A great attention to the topic has been drawn within both communities of remote sensing and forestry. Examples are a number of sensor-specific and general reviews on remote sensing applications for retrieval of forest inventory that have published by prominent international journals within a decade [4–9]. The latter review addressed the four main remote sensing technologies of airborne and terrestrial laser scanning (ALS and TLS), digital aerial photogrammetry, high spatial resolution and very high spatial resolution satellite imagery as the main pillars of research for remote sensing-assisted forest inventory [9]. In addition, and with the recent advancements in optical earth observation data with spatial resolutions ≤30 m and temporal resolutions ≤16 days (Landsat-8 OLI and Sentinel-2 data), multi-phase remote sampling techniques and multi-scale mapping of inventory attributes are now more and more fostered worldwide.

2. Summary of the Published Contributions

Motivated by the recent trends and global interest, the Remote Sensing special issue "Remote Sensing-Based Forest Inventories from Landscape to Global Scale" hosted nine peer-reviewed papers adopting various modern applications of passive and active remote sensing data for multi-scale forest inventory applications. This special issue is enriched with a series of independent, though contextually related, recent studies from diverse geographical domains of the globe, including the near-Arctic Canada [10], Northern United States [11,12], Northern Japan [13], Southern Spain [14,15], Central Italy [16], Southern Poland [17] and Western Germany [18].

Contextually, all papers dealt with the three general topics of "remote sensing", "forest inventory" and "scale", though the topics are occasionally more focused in the individual contributions. To name a few concrete examples, [14] exclusively focused on the multi-scale solutions for expanding aboveground biomass (AGB) predictions from stand (high-resolution ALS data) to national (coarse-resolution MODIS data and topography), which resulted in comparatively high upscaling performance from an independent validation (R^2 = 0.70 and RMSE = 10.25 t ha^{-1}). A multi-scale approach was also followed by [18], in which a double-sampling approach based on ALS and optical satellite (SPOT-5 and RapidEye) data as auxiliary information was suggested to extend district-level to state-level estimations. This was shown to reduce the variance of the one-phase simple random sampling estimator by an average of 43% and 25% for district and state levels, respectively. Furthermore, scale was also addressed by a number of other papers in a range of realms, for example by [12] (spatial aggregation of field and image objects for co-registration) and [10] (tree- and plot-level estimation of height and basal area by means of stereo WorldView-3 imagery). All in all, drawing attention to the general topic of scale (as one of the challenging, yet still insufficiently addressed issues in forestry remote sensing) was definitely within the essential focuses when abstracting this special issue by the guest editors, which was well represented via a number of original studies published here.

In terms of forest attributes under focus, again, the published papers within this special issue covered a range of essential forest entities for inventory as well as for monitoring. Allometric tree and stand attributes were given considerable attention, with the aboveground biomass (AGB) being modelled in three of the nine studies [13–15], followed by growing stock [18], basal area [10] and tree height [10,11,13]. A remarkable insight was especially given by [15], who applied metrics from ALS for simultaneous estimation of soil organic carbon and the AGB, pertaining these together as essential stand characteristics that can be largely affected by thinning. Moreover, high-resolution canopy-related spectral and ALS-derived attributes were also leveraged by [11] to estimate tree count across canopy cover classes (with r^2 reaching 0.93 when using ALS metrics), whereas medium-resolution but multi-temporal classifications of forest and tree species types by [17] returned promising performances of accuracies >80% by incorporating refinements like topography and stratification. Spectral information from multi-temporal, optical Landsat imagery was also shown by [16] to enable good approximations for forest recovery via the use of multiple vegetation indices, highlighting the tremendous information content within the time series of medium-resolution satellite imagery for monitoring forest stand dynamics on a regional scale and beyond. Finally, [12] followed the important though often underestimated preprocessing step of image co-registration by suggesting a simulated solution based on spatial aggregation over adjacent pixels, which helps with precisely quantifying the co-registration error between the ground control points and satellite data.

Last but not least, the studies published within this special issue addressed the use of data from various sensor types, both from passive and active as well as from mono- and multi-temporal domains. A major emphasis was put on sole or combined use of ALS point clouds [11,13–15,18], which is a prudent choice when dealing with the inventory of forest structural variables on landscape to regional scales. Moreover, very high resolution, often mono-temporal satellite imagery (UAV and aerial photogrammetry, WorldView-3 data), was employed by [10,11,13], which mainly aimed at quantifying local forest structural details at high geometric resolutions. High-resolution optical data, including RapidEye and SPOT with geometric resolutions <10 m, were applied by [18], whereas medium-resolution (Landsat and Sentinel-2 series) [12,16,17] and low-resolution [14] data were also represented, mainly due to their proven ability for monitoring forest dynamics over timespans. In this realm, further applications of such multi-temporal series of data for regional and statewide inventory and analysis of forest structure and health are expected in the near future, either standalone or in combination with other costly, i.e., high resolution, sources of data.

Summing up, the series of published research within this special issue aimed to use the high visibility of *Remote Sensing* and the Open Access domain to add a milestone to the existing body of knowledge on forest inventory applications of modern remote sensing data and methods. This was done by careful selection of renowned international reviewers, thorough and patient review processes and manifold circulations with the authors and reviewers, which guaranteed hosting studies presenting high quality and partially groundbreaking applications of remote sensing data, in particular in harmony with the main focus of the special issue, namely emphasizing the potential of the existing data and methods for "multi-scale" applications, on which we believe a significant portion of future research should be directed.

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