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Editorial

Current Trends in Forest Ecological Applications of Three-Dimensional Remote Sensing: Transition from Experimental to Operational Solutions?

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Abstract: The alarming increase in the magnitude and spatiotemporal patterns of changes in composition, structure and function of forest ecosystems during recent years calls for enhanced cross-border mitigation and adaption measures, which strongly entail intensified research to understand the underlying processes in the ecosystems as well as their dynamics. Remote sensing data and methods are nowadays the main complementary sources of synoptic, up-to-date and objective information to support field observations in forest ecology. In particular, analysis of three-dimensional (3D) remote sensing data is regarded as an appropriate complement, since they are hypothesized to resemble the 3D character of most forest attributes. Following their use in various small-scale forest structural analyses over the past two decades, these sources of data are now on their way to be integrated in novel applications in fields like citizen science, environmental impact assessment, forest fire analysis, and biodiversity assessment in remote areas. These and a number of other novel applications provide valuable material for the *Forests* special issue "3D Remote Sensing Applications in Forest Ecology: Composition, Structure and Function", which shows the promising future of these technologies and improves our understanding of the potentials and challenges of 3D remote sensing in practical forest ecology worldwide.

Keywords: 3D remote sensing; composition; forest ecology; function; structure

1. Introduction

The research on understanding the underlying ecological processes of forest ecosystems has been amongst the main interests in natural sciences for centuries. A high number of text books written by forest ecologists on forest ecology are available, in which basic concepts (e.g., ecological functions, interrelated patterns, flora, fauna and their dynamics) and detailed topics (e.g., connection to other ecological branches like community or population ecology, energy flux, complexity and regeneration patterns in forest ecosystems) are elaborated either as a whole [1–3] or by considering specific global biome- and ecosystem-specific characteristics [4–6]. However, one may note that common ecological concepts like biodiversity, ecosystem functioning and structure are overly multi-dimensional and cannot be subject to crisp definitions [7].

By defining a framework to answer most ecological questions one may, however, also note the structure of forest landscapes in general, which is inherently complex and three-dimensional (3D). This is mainly raised by the presence and dynamics of vegetative elements that harmonize with factors like topography, wildlife and climatic variables. This complexity has necessitated that researchers selectively focus on a subset of forest ecological components, while neglecting others in a given research framework [8]. Regardless of the degree in which problems concerning forest structural, compositional and functional traits are simplified, the 3D nature of forest ecosystems stands as one of the most essential aspects influencing almost the entire ecosystem dynamics, and should therefore be given the highest consideration.

Bearing this in mind and given the tremendous difficulties associated with the logistics, manpower and temporal repeatability of field-based surveys for forest ecological research, various available sources of data acquired by space-borne, air-borne and terrestrial remote sensing sensors have nowadays become indispensable sources of information for research on spatiotemporal dynamics of forest ecosystems. However, here we deliberately focused on 3D sources of data due to (1) their higher semantic association with most concepts and attributes in forest ecology and (2) the existing dearth of collective research summary (e.g., reviews, proceedings and journal special issues) on their applications in forest ecology.

There are currently several sources of remotely sensed 3D data available that can be useful for forest applications. Space-borne sources range from stereo pairs of optical, multi-angular, satellite sensors [9,10] to synthetic aperture radar (SAR)-based measurements [11,12] and space-borne laser scanning [13]. The airborne sources are much more diverse, including airborne laser scanning [14–16], airborne SAR [17], and traditional stereo airborne photogrammetry [18,19]. These also include many of those surveyed from unmanned aerial vehicles (UAVs), for which structure from motion [20] has become a predominant source of 3D information, while the availability of light-weight devices like LiDAR [21] and other nanosensors improves each year. There is also a large range of plausible combinations of sensors to measure or estimate forest variables from terrestrial platforms (terrestrial laser scanning [22,23], portable profiling lidar [24], fish-eye [25] and traditional stereo-photogrammetry [26], and even GPS receivers [27]). Each of them has distinct limitations in spatial and temporal coverages and the associated costs. Whereas each data source, individually or as categorized (optical stereoscopic, interferometric or polarimetric SAR and laser scanning), is associated with its specific analytical data processing, pros and cons, what they all have in common is that they reflect the 3D nature of forest ecosystems on different levels and are thereby currently of great interest for both forest science and practical forestry. Despite the rather long-studied and conventional application of 3D information in fields such as predictive modeling of forest structural attributes [14] and modeling biodiversity measures like abundance and occurrence of animal assemblages and habitat characterization [28], forest fire regimes [29], or environmental impact assessment of civil engineering projects, the use of 3D information in forest landscapes is still considered novel and many aspects require further investigation. In addition, attention has been recently drawn to integrating 3D data and methods in practical forest ecosystem survey and management, which is mainly motivated by (1) reduced costs of data acquisition (in particular terrestrial and airborne data) [30] and (2) integration and fusion of data from multiple sources, including spatially high-resolution 3D data and spatially-extensive, and often free-of-charge, multispectral optical data using novel algorithms [31].

2. Summary of the Contributions

As mentioned above, there is currently a lack of collective research reports, yet an increasing interest on novel and integrative researches on forest ecology by means of 3D sources of remote sensing data. Thus, the *Forests* special issue “3D Remote Sensing Applications in Forest Ecology: Composition, Structure and Function” was conceptualized by the authors of this paper and finally hosted 10 peer-reviewed contributions in which 3D sources of remote sensing data were applied either as a preliminary or auxiliary sources of information to understand, classify, augment, model and predict forest ecological attributes. Geographically, the contributions published within this special issue were well distributed around the globe, including China (four contributions) [32–35], Canada [36], Germany [37], India [38], Iran [39], Panama [40] and the United States [41]. The geographical distribution of the countries in which the published contributions were carried out are summarized in Figure 1.

In terms of global climatic regimes and ecological biomes, the temperate biome included the majority of works with seven studies [33–37,39,41], followed by sub-tropical [32,38] and tropical [40] biomes.

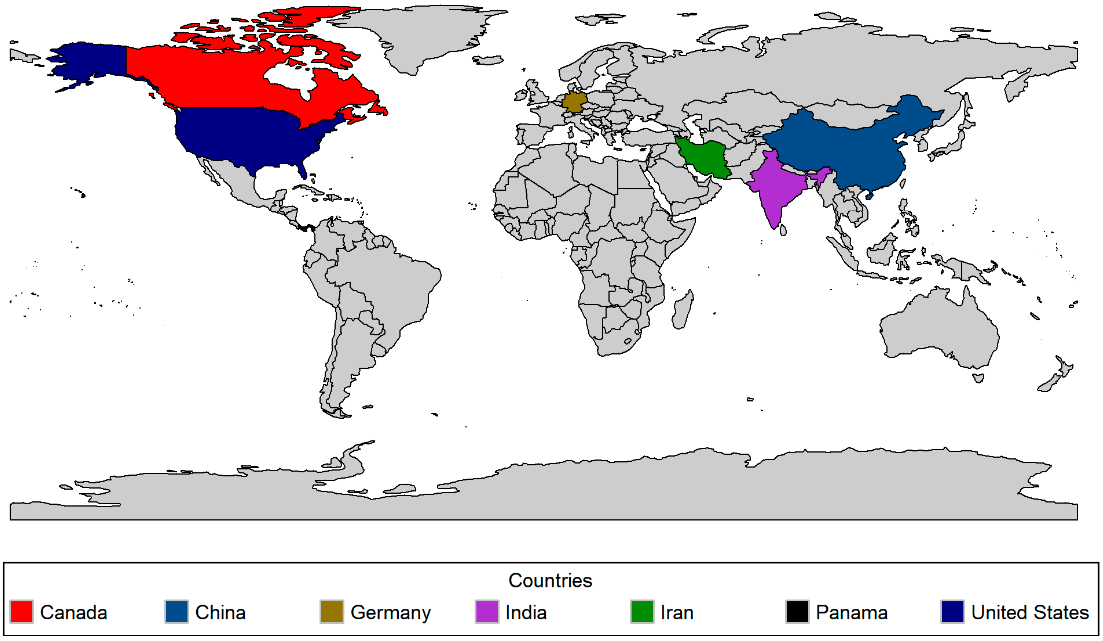

Figure 1. Distribution of the countries in which the study sites were located.

The topics covered within the published contributions can be divided into multiple groups: There were studies with rather classical applications such as single tree-level prediction of forest structural attributes by terrestrial laser scanning or visual estimation from Google Street View [33,41] and area-based prediction of forest structural attributes by space-borne stereo imagery, laser scanning or combination of passive optical with multi-frequency SAR data [34,35,39]. As an example, Ataee et al. [39] proved that a combination of space-borne SAR and optical data could improve performance and reduce uncertainties in the retrieval of tree volume. A number of works conducted on novel domains were also published, including a correlation between forest spectral burned ratios and height metrics derived from terrestrial laser scanning (using rather conventional height metrics for a novel application) [36], followed by other papers on hitherto rarely-studied topics like association between post-harvest tree root collar geometry and stump height by terrestrial laser scanning [37] and combining space-borne spectral and 3D data for fractional cover mapping of invasive alien woody species [38]. Moreover, Vallejos et al. [40] focused on a crucial, yet often neglected, source of statistical problem caused when working with optical remote sensing on quantitative ecological data, co-dispersion errors and data noise, whose results can be directly generalized to any existing source of 3D data. Similarly, habitat fragmentation caused by civil projects in forest ecosystems was surveyed by Li et al. [32], who addressed a generally remarkable topic that can be extended to similar cases using or combining 3D data sources like UAV-borne digital surface models. Here, the editors were open to those submissions with the main rationale that covering such crucial but still marginal topics might succeed in motivating extended research conducted on real 3D data. All in all, the published papers followed no biased tendency towards any specific group of relevant methodical or data-driven topics, but care was instead taken to host a collection of common applications that are currently in transition from being pure experimental to being implemented by the practitioners, together with those that are currently subject to no intensive research but contain great potential to be further addressed by the research community.

In terms of forest ecological attributes, the published papers represent a wide variety of attributes and thereby reflect the utterly diverse range of forest ecological attributes. As partly discussed above, the variables range from continuous variables that are commonly subject to regression modeling (allometric tree and stand structural attributes, root geometry, edaphic variables) [33–35,37,39–41] to categorical attributes that are relevant for classification approaches (fractional cover estimations of invasive species, landscape fragmentation) [32,38] and even to the use of vegetation indices and ratios [32,36]. One may, however, note that the current and potential applications of 3D remote sensing data in forest ecological domain go far beyond those covered here, with some examples being characterization of flora and fauna, coastal ecosystems, plant biodiversity (i.e., species richness), abiotic and biotic forest disturbances, sample size/sampling grid optimization for reference data surveys and many more. Therefore, we encourage further special issues focusing on publishing works on those subjects, in particular using state-of-the-art sources of 3D data such as space-borne laser scanning (e.g., ICESat-2 GLAS altimetry), space-borne C and L band interferometry (e.g., Sentinel and ALOS-2 data) and very high spatial resolution space-borne stereo optical data (e.g., SPOT 6-7, Pléiades 1A/1B, KOMPSAT series as well as SuperView-1 data from the GaoJing satellite).

A future pillar of research should also specifically concentrate on strengthening data assimilation and integrated use of multiple high- and medium-spatial resolution data sources. Recently published examples of such data assimilations are UAV with freely available optical data [42] and terrestrial laser scanning with multimodal space-borne data [43] for retrieving forest structural attributes. For forest ecological applications, this would concretely mean enhanced potentials for important practical applications like large-area calibrations of local models, monitoring remote and inaccessible mountainous forest ecosystems, calibrating small-area observations with large-area data on animal movements, and studying large-area habitat fragmentations. Therefore, we strongly encourage the remote sensing and forest ecological communities to intensify work transitioning from pure experimental data and methods to large-area practical applications, which could soon get enough popularity to be a topic for a future special issue of *Forests*.

Finally, this special issue was privileged by the high visibility and credibility of *Forests* in the Open Access domain to host a series of high-quality papers conducted by renowned international researchers. Nevertheless, the authors of this editorial treasure this opportunity to welcome future calls for similar relevant topics with a more practical orientation, possibly with a degree of financial incentives offered by MDPI to reduce publication fees. This would further support hosting quality research works and would enhance the visibility of both *Forests* and the published remote sensing/forest ecological works therein.

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