A New Look Beneath the Canopy — large-scale assessment of patterns and drivers of understory structure in and around Central European protected forests.

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The rapid decline in biodiversity represents one of today's most critical ecological challenges. Forest ecosystems are central to addressing this issue, as they provide habitat for a large proportion of global species and deliver essential ecosystem services. In Central Europe, forests are highly fragmented and embedded within densely populated landscapes, where they must simultaneously fulfill roles such as timber production, recreation, and climate regulation. This creates significant tension between conservation goals and societal or economic demands, prompting debates among stakeholders over which areas to prioritize for protection.

A viable indicator for assessing habitat quality is forest structure, as late-seral stages are characterized by high structural complexity and heterogeneity. Transitions into these stages take decades to centuries; therefore, information about structural complexity in existing protected areas provides a status quo of habitat quality and can inform the selection of new protected areas. Traditional methods for mapping structural complexity using forest mensuration techniques are labor-intensive, but advances in close-range remote sensing such as LiDAR offer new opportunities. Applied from airborne platforms, LiDAR can capture large areas efficiently, but it is often limited in mapping structural attributes below the canopy—where most species dwell—necessitating terrestrial deployments to capture understory structure accurately.

Full-waveform LiDAR sensors offer unmatched precision for capturing forest structural attributes. However, their acquisition costs are high, and the common tripod-based setup typically requires a two-person team, making data collection labor-intensive. Discrete-return LiDAR sensors are comparably affordable and can be deployed by a single operator, but they are susceptible to occlusion effects as they record only the first return of a laser pulse, introducing considerable uncertainty.

To address some of these limitations, we developed a voxelization workflow using handheld mobile laser scanning to quantify understory structure and complexity. Our approach draws on a custom ray-tracing algorithm developed for a common discrete-return mobile laser scanner (GEOSLAM ZEB Horizon), using both the point cloud and trajectory data. The workflow augments information about unfilled space in open areas where the laser did not return any hit and quantifies uncertainties by classifying occluded and "modeled" empty voxels. We use spatial occupancy metrics such as density, 26-neighbor connectivity, and a relative partitioning index of vertical vegetation distribution.

We applied this framework along more than 250 line transects across boundaries of 44 protected areas in Bavaria, covering understory information for over 80 ha and representing major forest types (riparian, upland, and mountain). Our results indicate that understory structure differs little between protected and adjacent forests during the first decades after designation. Boundaries of protected areas often stand out from their surroundings; however, this effect occurs both inside and outside protected areas, likely reflecting the common practice of aligning boundaries with stand edges or forest roads.

Our voxelization-based approach enhances the informative value of mobile laser scanning datasets by improving understory assessment and explicitly quantifying uncertainty caused by occlusion in discrete-return sensors. This workflow provides a more robust basis for interpreting structural complexity in forest stands. Our field assessment offers insights into the current structural status of protected areas in Bavaria and can support planning and policy development for the selection, configuration, and management of newly protected areas.