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Point density and spatial resolution limit estimation of Leaf Area Index using discrete return LiDAR

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The total leaf area supported by a canopy, characterised by the Leaf Area Index (LAI), is one of the fundamental functional traits of forest ecosystems, underpinning biogeochemical cycles and surface energy balance, and mediating microclimate and habitat provision. Airborne LiDAR has emerged as a powerful method to measure LAI (or more specifically the Plant Area Index, PAI) and its variation across landscapes. However, survey characteristics such as point density exhibit high variance, even within the same survey dataset, due to factors such as flight line overlap and topography. Understanding how variations in point density influence estimation of PAI is therefore important in order to design and implement better surveys and correctly interpret associated uncertainties and biases.

We derive analytical solutions describing the relationships between the point density of a discrete LiDAR survey and the maximum PAI that can be detected, and between the spatial resolution at which the point cloud is aggregated and the corresponding PAI estimates. We compare these predicted relationships against observations from a survey across a structurally diverse forested landscape in Malaysian Borneo. We show that the theoretical maximum observable PAI increases with point density in a predictable way following a logarithmic function. We also show that averaging the point cloud over a greater area imposes a negative bias in corresponding PAI estimates, and that this bias scales with canopy heterogeneity, but that it is possible to correct for this if the fine-scale spatial distribution of PAI is known, or can be estimated from representative regions of the forest canopy sampled at much higher resolution.