LiDAR: What Can It Measure and How Can It Best Be Used?

LiDAR stands for light detection and ranging. It is a remote sensing (RS) technique that fires laser pulses at objects such as vegetation and the earth surface, and records the returns giving very precise three-dimensional locations for what the laser reflected from. LiDAR point clouds are used to reconstruct vegetation and ground surface conditions, and analyzed for landscape-level assessments and visualization (Fig. 1) across multiple ownerships. LiDAR is particularly valuable for assessing forest conditions and identifying strategic locations for allocating limited resources to improve forest resilience to wildfire and drought. For programs such as CalFire's Forest CA Climate Investment Grants (FH-CCIG) and California's Air Resources Board GHG inventory and emissions estimates, it can provide accurate and extensive measures of forest carbon, fire and thinning effects on forest health and resilience, and potential carbon emissions.

LiDAR is particularly good at assessing conditions that traditional forestry sampling is poor at measuring because its ground based and plots are limited in size and number. These include how much **carbon** a forest is holding[1], key **wildlife habitat** such as the spotted owl[2], **and a forest's resilience to future fire and drought**[3]. Recently developed LiDAR methods[4] can measure how forests are affected by management practices such as mechanical thinning (Fig. 2) and prescribed or managed fire, and whether these treatments produce healthy forests with stable carbon stores.

Attributes that LiDAR can assess, approximately ordered from most to least robust:

Attribute:	Strengths	Weaknesses
Forest inventory	Detailed measures of tree height, canopy cover & tall dead trees providing highly accurate estimates of forest conditions.	Cannot provide total stem density because understory trees are not always detected.
Carbon	Excellent estimates of carbon and total biomass from stands to landscapes.	Limited measure of down wood & surface fuels, a small portion of total C.
Restoration & resilience	Robust assessments of forest structure, particularly of tree spatial patterns, which provide wildfire and drought resilience.	Can roughly detect sub-canopy trees and shrubs (presence/absence), but best measures are of overstory trees.
Wildlife habitat	Excellent for measuring canopy habitat for birds and arboreal mammals.	Under dense canopy cover limited assessment of understory habitat.
Fuel conditions	Good estimates of canopy fuels, but these are the least influential on fire behavior.	Limited assessment of sub-canopy trees (ladder fuels) & surface fuel loading which strongly influence fire intensity.
Change through time*	One-time, detailed, accurate landscape assessment.	Change detection requires repeated LiDAR acquisitions*.

Measurements: The high-frequency laser pulses can penetrate the upper canopy providing a much fuller measure of a forest's three-dimensional structure. LiDAR is less accurate at measuring sub-canopy conditions such as ladder and ground fuels unless the forest is open or a high-density of laser pulses are acquired (see considerations). LiDAR, however, can be combined with ground-based measurements of the forest floor to improve fuels assessments.

Implementation: CalFire could directly **use LiDAR to identify priority locations for FH-CCIG treatment such as forests with large but unstable carbon stocks** because they are in locations likely to burn or are susceptible to drought mortality due to limited site water availability. This would optimize the allocation of funds and reduce potential smoke emissions and carbon loss. CalFire would have better estimates of current conditions and the longer-term carbon benefits of proposed projects. After implementation, repeat LiDAR can assess treatment efficacy. This approach could provide a common statewide platform integrating project-scale inventories of forest carbon and resilience while strategically allocating limited resources.

Considerations: LiDAR acquisitions have different standards ranging from QL1 (a high laser pulse density [> 8 returns/m^2] and 50% overlap in each flight line), to quicker, less intensive standards. Costs vary accordingly, with the highest QL1 standard averaging about $1/acre.

**Promising:* There is great potential for overcoming LiDAR's snapshot limitation if its detailed assessments can be 'crosswalked' to refine other RS methods that frequently image changes in forest conditions and validate other forest monitoring RS products (ex. Digital Aerial Photogrammetry [DAP] a lower cost, less detailed method collected every two years). Satellite platforms are also being tested for their integration with LiDAR data and some of these, such as Landsat have many years of data, are collected frequently (every 16 days since 1984) and are free. Good 'crosswalks' are already improving the accuracy of other RS methods and are expanding forest inventories beyond LiDAR's footprint[5].

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[3] Koontz, M.J., M.P. North, C.M. Werner, S.E. Rick and A.M. Latimer. 2020. Local forest structure variability increases resilience to wildfire in dry western U.S. coniferous forests. Ecology Letters. doi: 10.1111/ele.13447.

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[5] Huang, S., C. Ramirez, M. McElhaney and K. Evans. 2018. F3: Simulating spatiotemporal forest change from field inventory, remote sensing, growth modeling and management actions. Forest Ecology and Management 415: 26-37.