Mapping Forest Inventory Parameters using Lidar

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Presentation Outline

• Considerations for using lidar technology when modeling forest inventory parameters
  - Lidar Specifications
  - Key Elements

• Case Study: Mapping Vegetation Structure in the Pinaleño Mountains Using Lidar - Phase 3: Forest Inventory Modeling
  - Methodology
  - Inventory Modeling Results
Ideal Lidar Acquisition Specifications for Inventory Modeling

- Discrete Airborne Lidar (Terrestrial – NIR)
- Pulse Density
  - > 3 pulses/m² (Vegetation Structural Modeling)
- Multiple Returns Per Pulse – 4 returns per pulse
- Narrow Beam Divergence - < 30cm
- Timing – Leaf On
- 50% side lap on swaths

Publication: *Practical Lidar Acquisition Considerations For Forestry Applications*
Lidar Pulse Density

1 pulse/meter

8 pulses/meter
Key Elements in Lidar Inventory Modeling

Plot Data

Explore Relationship

Build Landscape Models

Legend

Basal Area (SqFt/Acre)
- High: 563
- Low: 3
Field plot location and consistency, is it important?

**Plot 9**
- Field Measured BA = 100
- 50th Height Percentile = 30.4
- \( \frac{\text{(All returns above mean)}}{\text{(Total first returns)}} \times 100 = 16.9 \)
- Max height in lidar = 61

**Plot 23**
- Field Measured BA = 100
- 50th Height Percentile = 69 (~double)
- \( \frac{\text{(All returns above mean)}}{\text{(Total first returns)}} \times 100 = 29.25 (~\text{double}) \)
- Max height in lidar = 85.44
Case Study: Pinaleño Mountains Lidar Inventory Mapping Project

- Pinaleño Mountains Sky-Island study area (~85,000 acres) on the Coronado National Forest.
Project Acquisition Specifications

- Acquisition date: September 2008; Leaf-On
- Scan angle: +/-15 degrees
- Beam divergence: 19 – 29 cm (narrow)
- Flight line configuration: Opposing/adjacent/parallel
- Flight line overlap: 50% sidelap (100% Overlap)
- Average lidar pulse density: 7.36 pulses/m^2
Pinaleño Field Data Collection

- 80 field plots
- .05 hectare in size
- Sub meter location accuracy
- All trees 3in DBH and greater were measured
- Sampling Design: systematic Grid
  - Alternatively you could stratify plot locations based on lidar data to ensure all structural conditions were sampled and increase efficiency
Forest Inventory Parameters

Parameters calculated on each plot and summed to plot level

- Biomass
- Total Basal Area
- Live Basal Area
- Height weighted by BA
- Volume
- Volume dead
- Stand Density Index
- Standard deviation of tree height
- Quadratic Mean Diameter
- Fuel Parameters
  - canopy bulk density
  - canopy fuel load
  - canopy base height
Create Lidar Plot Metrics

- **Subset plot locations** (based on field plot coordinates)
  - .05 Hectares = approximately 25 meter diameter
- **Calculate canopy metrics** on each new Plot Subset

---

<table>
<thead>
<tr>
<th>Total number of returns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count of returns by return number (support for up to 9 discrete returns)</td>
</tr>
<tr>
<td>Minimum</td>
</tr>
<tr>
<td>Maximum</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Median (output as 50th percentile)</td>
</tr>
<tr>
<td>Mode</td>
</tr>
<tr>
<td>Standard deviation</td>
</tr>
<tr>
<td>Variance</td>
</tr>
<tr>
<td>Coefficient of variation</td>
</tr>
<tr>
<td>Interquartile distance</td>
</tr>
<tr>
<td>Skewness</td>
</tr>
<tr>
<td>Kurtosis</td>
</tr>
<tr>
<td>AAD (Average Absolute Deviation)</td>
</tr>
<tr>
<td>L-moments (L1, L2, L3, L4)</td>
</tr>
<tr>
<td>L-moment skewness</td>
</tr>
<tr>
<td>L-moment kurtosis</td>
</tr>
<tr>
<td>Percentile values (1st, 5th, 10th, 20th, 25th, 30th, 40th, 50th, 60th, 70th, 75th, 80th, 90th, 95th, 99th percentiles)</td>
</tr>
</tbody>
</table>

In addition to the above metrics, CloudMetrics also computes various ratios of returns above a heightbreak when the /above switch is used:

- Percentage of first returns above a specified height (canopy cover estimate)
- Percentage of first returns above the mean height/elevation
- Percentage of first returns above the mode height/elevation
- Percentage of all returns above a specified height
- Percentage of all returns above the mean height/elevation
- Percentage of all returns above the mode height/elevation
- Number of returns above a specified height / total first returns * 100
- Number of returns above the mean height / total first returns * 100
- Number of returns above the mode height / total first returns * 100
Lidar Inventory Modeling: Explore Relationships

- **Regression Modeling** (plot level)
  - Explore the relationships between field plot measurements and correlating lidar plot metrics
  - Linear Modeling to find best predictor variables
  - Maximized fit using Nonlinear Models

<table>
<thead>
<tr>
<th>Parameter</th>
<th>P1</th>
<th>P2</th>
<th>Linear $R^2$</th>
<th>Nonlinear $R^2$</th>
<th>Nonlinear Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass Mean Hght</td>
<td>Mean Hght</td>
<td>(all returns above mean) / (total first returns) * 100</td>
<td>0.7415</td>
<td>0.8779</td>
<td>$z = \frac{(ax/b - cy/d)}{(1 + x/b + y/d)} + \text{Offset}$</td>
</tr>
<tr>
<td>Basal Area Elev P75</td>
<td>Elev P75</td>
<td>(all returns above mean) / (total first returns) * 100</td>
<td>0.7023</td>
<td>0.7782</td>
<td>$z = a + bx + cy + dx2 + fy2 + gx3 + hy3 + ixy + jx2y + kxy2$</td>
</tr>
<tr>
<td>Trees per Hectare var</td>
<td>10th Percentile height</td>
<td>0.1664</td>
<td>0.2947</td>
<td>$z = \frac{(a + b\ln(x) + c\exp(y) + d\ln(x)\exp(y))}{(1 + f\ln(x) + g\exp(y) + h\ln(x)\exp(y))} + \text{Offset}$</td>
<td></td>
</tr>
</tbody>
</table>
Create Lidar Grid Metrics

- Calculate canopy metrics across entire landscape as grid layers – 25m cell size correlating to plot size
Apply Inventory Models at the Landscape Level

- Apply regression equation to the Landscape using the Raster Calculator tool for ArcGIS

Equation for Biomass = \( \frac{ax/b - cy/d}{1 + x/b + y/d} + \text{Offset} \)

\[
a = -2.7375875450033640 \times 10^4
\]
\[
b = -2.3665464379090434 \times 10^1
\]
\[
c = -1.2228895147411651 \times 10^6
\]
\[
d = 9.4128309407458164 \times 10^2
\]
\[
\text{Offset} = 1.4279090512283406 \times 10^3
\]

\( X = \text{Mean Height} \)

\( Y = \text{(all returns above mean/(total first returns)} \times 100 \)
Resulting BioMass Inventory Model

- **Masking and validation** of final model
  - Values outside the range of plot metrics (extrapolation points)
  - Validate Model Performance
## Inventory Models Created

<table>
<thead>
<tr>
<th>Parameter</th>
<th>P1</th>
<th>P2</th>
<th>Linear ( R^2 )</th>
<th>Nonlinear ( R^2 )</th>
<th>Nonlinear Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass Kg per Hct</td>
<td>Mean Hght</td>
<td>(all returns above mean) / (total first returns) * 100</td>
<td>0.7415</td>
<td>0.8779</td>
<td>( z = (ax/b - cy/d) / (1 + x/b + y/d) + \text{Offset} )</td>
</tr>
<tr>
<td>HGTwBA</td>
<td>Elev Mean</td>
<td>Elev Skewness</td>
<td>0.8123</td>
<td>0.8265</td>
<td>( z = a + bx + cy + dx^2 + fy^2 + gx^3 + hy^3 )</td>
</tr>
<tr>
<td>Volume</td>
<td>Elev P60</td>
<td>(all returns above mean) / (total first returns) * 100</td>
<td>0.7026</td>
<td>0.8216</td>
<td>( z = (a + b\ln(x) + c\ln(y) + d\ln(x)\ln(y))/(1 + f\ln(x) + g\ln(y) + h\ln(x)\ln(y)) )</td>
</tr>
<tr>
<td>Basal Area Total</td>
<td>Elev P75</td>
<td>(all returns above mean) / (total first returns) * 100</td>
<td>0.7023</td>
<td>0.7782</td>
<td>( z = a + bx + cy + dx^2 + fy^2 + gx^3 + hy^3 + ixy + jx^2y + kxy^2 )</td>
</tr>
<tr>
<td>Basal Area Live</td>
<td>Percentage all returns above mean</td>
<td>0.0599</td>
<td>0.67</td>
<td>( z = 0.0153x^2 + 0.9306x - 3.8899 )</td>
<td></td>
</tr>
<tr>
<td>CBH (canopy base height)</td>
<td>Elev Var</td>
<td>Elev CV</td>
<td>0.4855</td>
<td>0.6186</td>
<td>( z = (a + b\exp(x) + c\exp(y) + d\exp(x)\exp(y))/(1 + fx + gy + hxy) + \text{Offset} )</td>
</tr>
<tr>
<td>CBD (canopy bulk density)</td>
<td>Elev P20</td>
<td>Percentage all returns above mean</td>
<td>.3724</td>
<td>.4378</td>
<td>( z = (a + bx + cy + dxy)/(1 + f\ln(x) + g\ln(y) + h\ln(x)\ln(y)) + \text{Offset} )</td>
</tr>
</tbody>
</table>
**Apply Forest Mask**

- Use conditional statements in Raster Calculator
  - Less than 3 meters canopy height masked out as non forest
  - Less than 2% canopy cover Masked out as non forest
Model Extrapolation Issues

Lidar metric: Mean Height
Plot Min: 2.468 meters  Project Min: 2.02
Plot Max: 20.725 meters  Project Max: 45.25

Lidar Metric: \(\frac{(\text{all returns above mean})}{(\text{total first returns})} \times 100\)
Plot Min: 1.155  Project Min: .0073
Plot Max: 81  Project Max: 95.33

Pixel Extrapolation %
Total Pixels = 515, 077
Within Range = 99.3% (511848 pixels)
Below Range = < .1 % (18 pixels)
Above Range = .6 % (3211 pixels)

Pixel Extrapolation %
Total Pixels = 515, 077
Within Range = 99.9% (514775 pixels)
Below Range = < .1 % (180 pixels)
Above Range = < .1 % (122 pixels)
Final Models

Biomass

$R^2 = .88$

Canopy Fuel Load

$R^2 = .6$

Canopy Base Height

$R^2 = .62$

Canopy Bulk density

$R^2 = .43$
Final Models

**Total Basal Area**
\[ R^2 = 0.78 \]

**Live Basal Area**
\[ R^2 = 0.67 \]

**Total Volume**
\[ R^2 = 0.82 \]

**Dead Volume**
\[ R^2 = 0.74 \]
The previously burnt area represented by a WorldView 2 High Resolution Satellite Image displayed in False Color (RGB = NIR, R, G).

Total Basal Area

Live Basal Area

### Total Basal Area

<table>
<thead>
<tr>
<th>Units: square meters / hectare</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.973640372 - 10</td>
<td></td>
</tr>
<tr>
<td>10.00000001 - 20</td>
<td></td>
</tr>
<tr>
<td>20.00000001 - 30</td>
<td></td>
</tr>
<tr>
<td>30.00000001 - 40</td>
<td></td>
</tr>
<tr>
<td>40.00000001 - 50</td>
<td></td>
</tr>
<tr>
<td>50.00000001 - 60</td>
<td></td>
</tr>
<tr>
<td>60.00000001 - 70</td>
<td></td>
</tr>
<tr>
<td>70.00000001 - 80</td>
<td></td>
</tr>
<tr>
<td>80.00000001 - 90</td>
<td></td>
</tr>
<tr>
<td>90.00000001 - 100</td>
<td></td>
</tr>
</tbody>
</table>

### Live Basal Area

<table>
<thead>
<tr>
<th>Units: square meters / hectare</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 10</td>
<td></td>
</tr>
<tr>
<td>10.00000001 - 20</td>
<td></td>
</tr>
<tr>
<td>20.00000001 - 30</td>
<td></td>
</tr>
<tr>
<td>30.00000001 - 40</td>
<td></td>
</tr>
<tr>
<td>40.00000001 - 50</td>
<td></td>
</tr>
<tr>
<td>50.00000001 - 60</td>
<td></td>
</tr>
<tr>
<td>60.00000001 - 70</td>
<td></td>
</tr>
<tr>
<td>70.00000001 - 80</td>
<td></td>
</tr>
<tr>
<td>80.00000001 - 90</td>
<td></td>
</tr>
<tr>
<td>90.00000001 - 100</td>
<td></td>
</tr>
</tbody>
</table>
Basal Area Model Exploration

A lower elevation region of the study area is represented below by a WorldView 2 High Resolution Satellite Image displayed in False Color (RGB = NIR, R, G).

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Units: Kg/Hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>61,178.9</td>
</tr>
<tr>
<td>Low</td>
<td>7,816.4</td>
</tr>
</tbody>
</table>

Model Logic Error
- Live BA exceeds Total BA
Closing Considerations

• If the plot locations are not accurate confidence in this modeling process is very low!!!!!!

• **Good sampling design will limit extrapolation points**
  - Use lidar derivatives of height and density to create a stratified sampling scheme

• **Regression Modeling is complex and has a element or artistry. You need a skilled analyst.**

• A local knowledge of the study area is needed to validate the models, **do they make sense??**
Acknowledgements

• Project Cooperators
  - Tom Mellin, Craig Wilcox, John Anhold, Dr. Ann Lynch, Dr. Don Falk, Dr. John Koprowski, Marit Alanen

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