Conservation Applications of LiDAR Data

Workshops funded by the Minnesota Environment and Natural Resources Trust Fund

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Workshops funded by:

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USDA Natural Resources Conservation Service

Minnesota Department of Natural Resources

tsp.umn.edu/lidar

Conservation Applications of LiDAR Data

Training Modules:

- Basics of Using LiDAR Data
- Terrain Analysis
- Hydrologic Applications
- Engineering Applications
- Wetland Mapping
- **Forest and Ecological Applications**

tsp.umn.edu/lidar

Andy Jenks
University of Minnesota, Dept of Forest Resources

Forestry Applications of LiDAR Data

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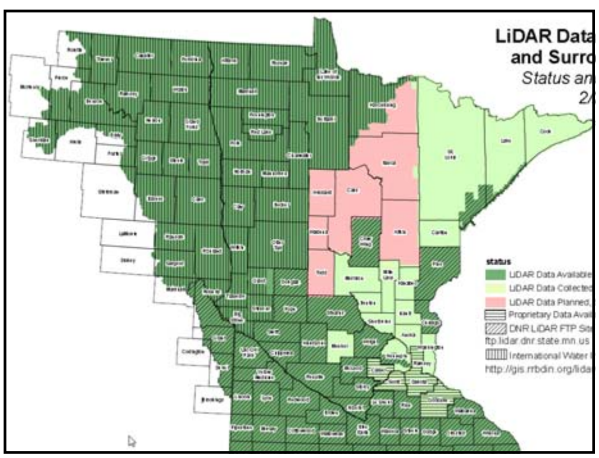


Two most important points of this class:

BIG DATA

INCREASED ACCURACY

Two most important points of this class:

BIG DATA (great… more detail, more area, more time periods)

INCREASED ACCURACY
(great .. Better answers, less waste, less confusion or uncertainty)

Two most important points of this class:

BIG DATA (now how do you deal with it?)

INCREASED ACCURACY
(now how do you deal with it?)

1m contours – no point thinning

1m contours – with point thinning

Two most important points of this class:

BIG DATA

INCREASED ACCURACY

<u>Be careful what you ask for</u>

ArcGIS
Coordinate Systems

Statewide → County Coordinates

Especially Datum Transfromations (Harn & CORS96, WGS84)

ArcGIS
GeoDatabase (everything all together)

<u>Feature Data Set</u> *(coordinates are stored here)*

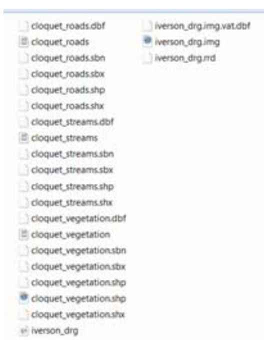
<u>Feature Data Class</u>
Vector layer
Vector layer
....

Raster layer
Raster layer
....

<u>Feature Data Set</u>

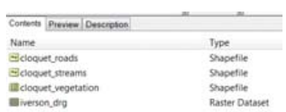
.....

View using Windows Explorer

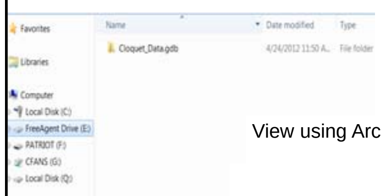


Shapefiles

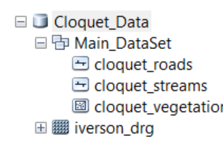
View using Arc Catalog



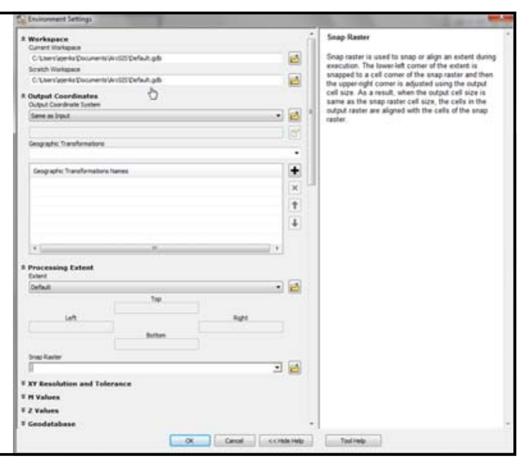
View using Windows Explorer



View using Arc Catalog



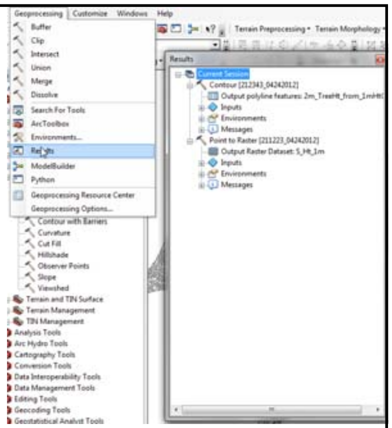
ArcGIS
Environmental Variables



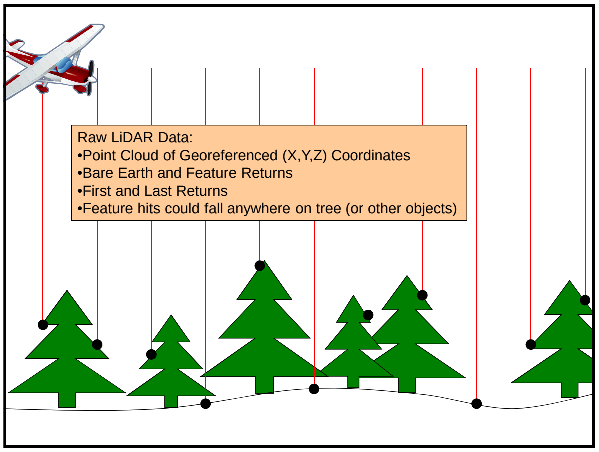
ArcGIS

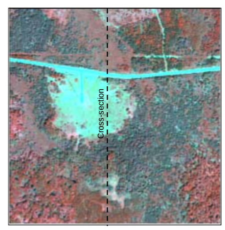
Results
(how to stop a
 process)

Environments

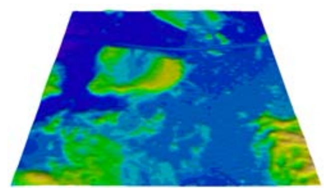


ArcGIS
Terrain Databases

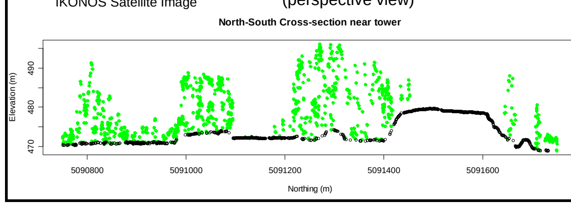




IKONOS Satellite Image

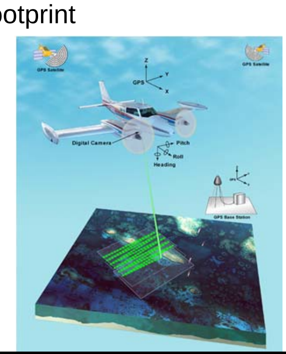


Lidar-derived elevation surface
(perspective view)

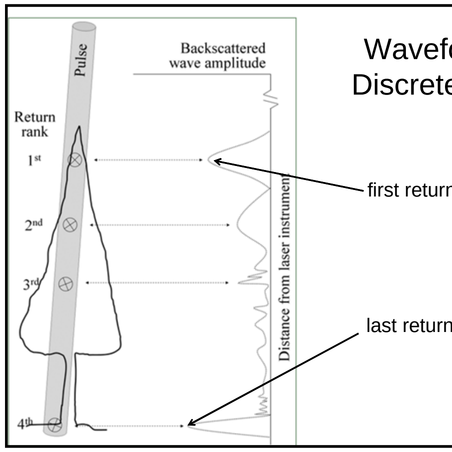


Properties of LiDAR Sample

- Beam and ground footprint
- Returns per pulse
- Density
- Angles
- Intensity Threshold



Waveform vs. Discrete Return



Ground Footprint

Beam specified by an angle, α, in milliradians

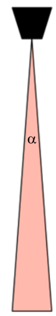
Beam width expands the farther from the source

Ground footprint depends on flying height and beam angle, α

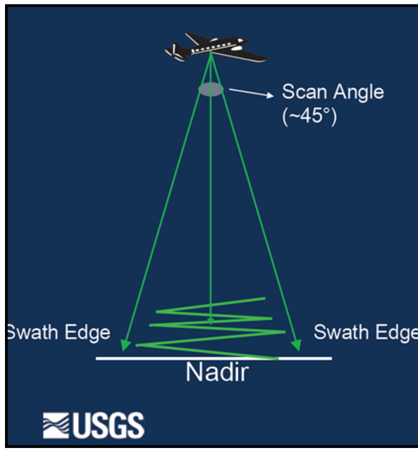
Ground footprints typically in the 15 to 50 cm (6" to 18") range

Larger ground footprint means lower energy returns, lower spatial precision

Smaller footprint for a given instrument means smaller area coverage, and/or sparser sample



Scan Angle



Swath limited, best angles less than 7 degrees

Height errors increase with angle, but beggars can't be choosers

Return Density

Mature Hardwood Forest
Kandiyohi County

Returns per square meter

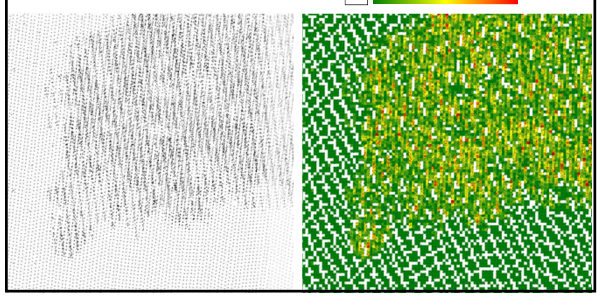
1 10

Return Density – Bare Patches

Returns near forest/water edge

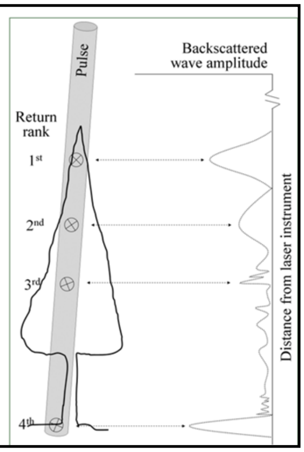
Returns per square meter

0 1 10

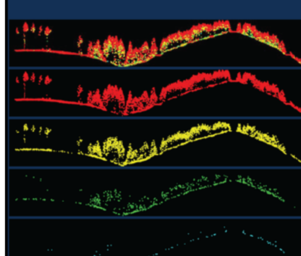


Multiple Returns

- Usually at least 2, 1st and last
- May be up to 4, two intermediate – threshold or ordinal selection



Multiple Returns



All returns (16,664 pulses)

1st returns

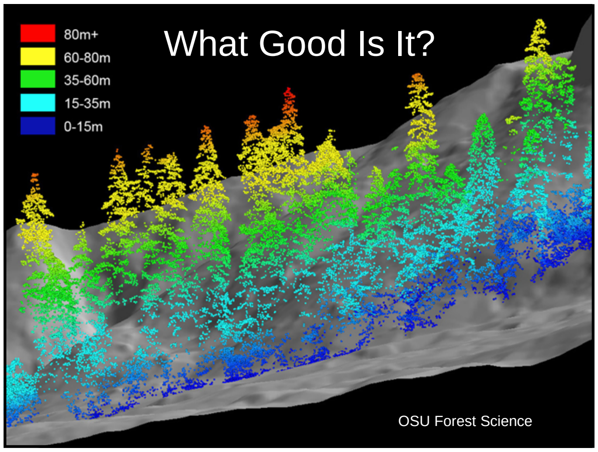
2nd returns (4,385 pulses, 26%)

3rd returns (736 pulses, 4%)

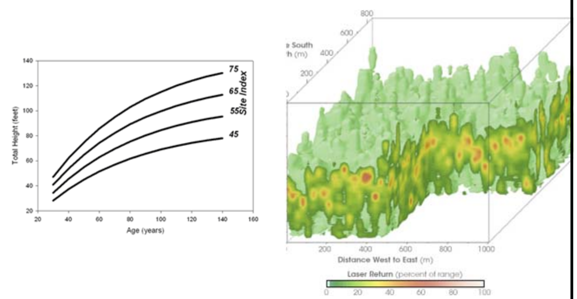
4th returns (83 pulses, <1%)

USGS

Image courtesy Hans-Erik Anderson

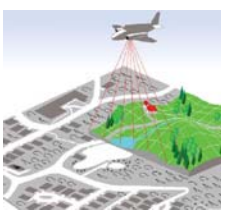


LiDAR Measures Canopy Height and Density

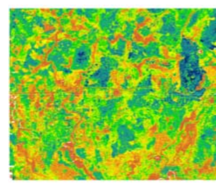


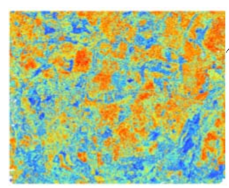
NASA

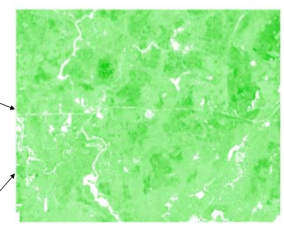
LiDAR Applications

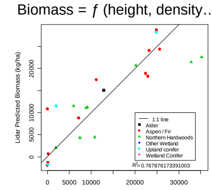

B. Cook, NASA

- Ground elevations
- Canopy heights
- Biomass
- New measurements
  - Growth
  - Leaf area
  - Percent cover
  - Stocking density
- Advantages
  - Cost efficient for large areas
  - High spatial resolution (~5 cm)
  - Numerous applications
    - Forest biomass, growth, carbon exchange
    - Vegetation type
    - Phenology, disturbance
- Analytical Challenge
  - Deciduous and mixed forests, nonforests


Canopy Height


Canopy Density

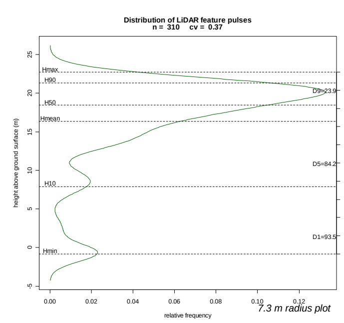

Biomass = *f* (height, density…)



Field Measurements

- •Height, diameter, species on every tree
- •Growth on every tree in central subplot
- •Age (for site index) on 1 tree per condition
- •CWD on 3 transects for each subplot
- •Hemispheric photos for LAI
- •Densiometer measure of canopy closure
- •Site condition, slope, aspect etc…
- •>150 plots

Lidar-Derived Quantification of Forest Structure



Hmin, Hmax, Hmean	Minimum, maximum, mean heights detected within plot
D1, D5, D9	The proportion of LiDAR canopy returns that were above the indicated number of 10 equal width intervals.
H10, H50, H90	Indicated Percentile of feature returns within plot
Hcv	Coefficient of Variation of lidar pulses within plot

Model Building

- All-possible-subsets regression

  Biomass = f (LiDAR metrics)

- Best models evaluated by Mallow's *Cp* statistic

$$C_p = \frac{SSE_p}{\hat{\sigma}^2} - n + 2p$$

- Leave-one-out cross-validation (predicted RMS error)

$$RMS = \sqrt{\sum_{i=1}^{n} (Y_i - \hat{Y}_i^*)^2}$$

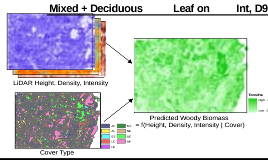
Where $\hat{Y}_i^*$ is the predicted value of the i^{th} case using the model fit excluding that case

- Kappa statistic to assess collinearity $\kappa = \frac{\sqrt{\lambda_1}}{\sqrt{\lambda_p}}$

Biomass Results

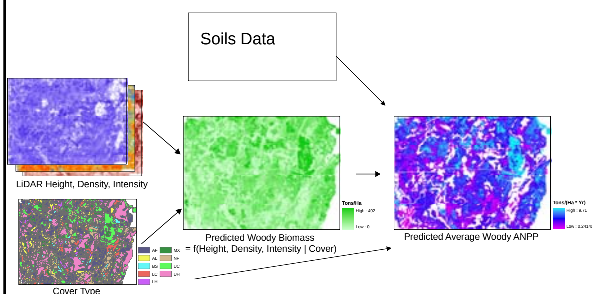
Best models by cover type

Cover Type	Dataset	Terms:	R2	n	Cross-validated RMSE (tons/Ha)
All Plots	Leaf on	Int, Hmean, D9	0.55	169	43.47
Aspen/Fir	Leaf on	Int, Hmean, D5	0.47	40	47.57
Alder	Leaf off	Int, H90, Hmax, MGI	0.95	11	14.09
Black Spruce	Leaf off	Int, H10, MFI, MGI	0.99	9	10.18
(N. White cedar)	Leaf on	Int, H10, MFI	0.73	27	25.39
Lowland Hardwoods	Leaf off	Int, H50, MFI, MGI	0.96	10	12.50
Upland Hardwoods	Leaf on	Int, D9, D1, Qmean	0.66	32	47.71
Upland Conifers	Leaf off	Int, Hmin, MG	0.74	16	48.64
Deciduous Forest	Leaf on	Int, D9, D1, Qmean	0.71	57	42.79
Coniferous Forest	Leaf off	Int, Hmin, Hmax, MFI	0.74	47	37.55
Mixed Forest	Leaf on	Int, H90, MFI, close	0.46	46	48.06
Mixed + Deciduous	Leaf on	Int, D9, D1, Qmean	0.5	103	46.20

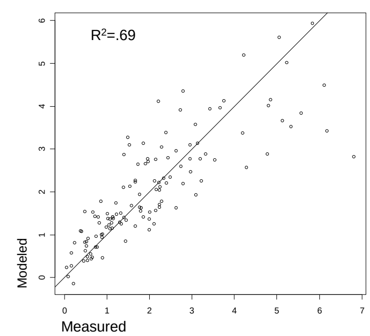


- Leaf-off and leaf-on give similar results
- Conifer types show strongest relationships
- Simple Conifer-deciduous breakdown seems adequate
- Mixed Cover types a problem
- Significant variability at the pixel level

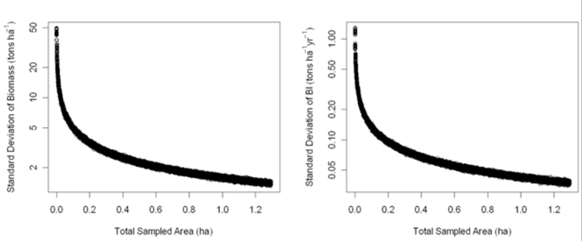
Basis For a Productivity Model



Basis For a Productivity Model



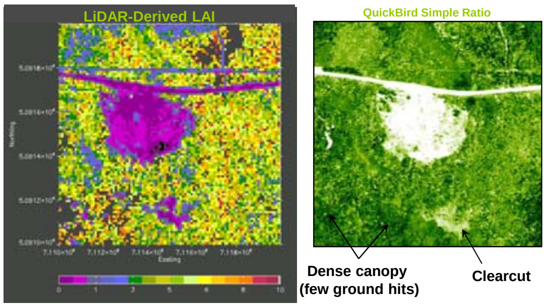
Accuracy Improves at Larger Areas



Progress, Future

- Improved estimates of biomass realized through LiDAR – across species, mixes, densities, space
- Components? Bole, branch, leaves?
- Extendable to shrub, herbaceous plants?
- Carbon cycling- belowground pools via terrain metrics

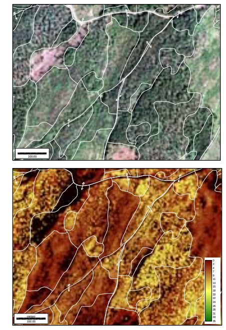
Leaf Area Index (LAI)



First return from leaf-on collection (10 m grid cells)
Mean LAI = 5.0

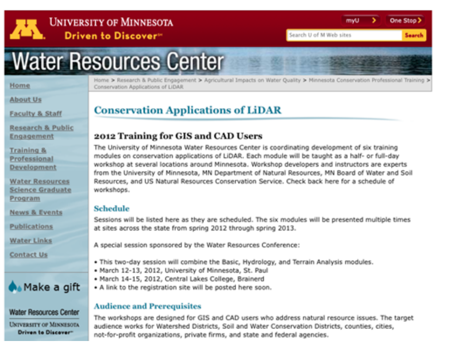
Methods for Operational Forest Inventory in Norway

- **Research going on since 1995**
- **Objective:** develop and validate LiDAR-based methods for detailed forest inventories providing data for management of individual forest properties
- **About 15 project funded by the Research Council and the forest industry in Norway, 1995-2008**
- **Partners:** UMB and local forest industry
- **Validation confirms:**
  - Accuracy 100% better than conventional methods
  - Costs 1/20-1/40 of conventional inventory



Våler study site, Norway (E. Næsset)

http://tsp.umn.edu/lidar



Two most important points of this class:

BIG DATA

INCREASED ACCURACY

Table 3. Allometric equations used to calculate biomass by species.

Common Name	Species	Source	Model Form	a	b	c	d	e	f
Balsam Fir	*Abies balsamea*	Young et al. 1980	A	0.005	2.4605	0.0679	2.4117		
Tamarack	*Larix laricina*	Young et al. 1980	A	0.0436	1.981	0.0762	2.3051		
White Spruce	*Picea glauca*	Harding and Grigal 1985	A	0.0248	2.40	0.0397	2.536		
Black Spruce	*Picea mariana*	Ker 1980, 1984	A	0.0287	2.2679	0.0849	2.313		
Jack Pine	*Pinus Banksiana*	Ker 1980, 1984	A	0.0353	2.1113	0.147	2.1673		
Red Pine	*Pinus resinosa*	Young et al. 1980, Perala and Alban 1994	B	0.0098	2.5011	0.0141	2.09	0.0649	2.3496
White Pine	*Pinus strobus*	Young et al. 1980	A	0.003	2.4838	0.0404	2.5459		
Alder	*Alnus sp (primarily alnus incana)*	Young et al. 1980	A	0.0617	1.5201	0.0463	2.5735		
Northern White Cedar	*Thuja occidentalis*	Young et al. 1980, Perala and Alban 1994	A	0.048	1.911	0.0832	2.13		
Eastern Hemlock	*Tsuga canadensis*	Young et al. 1980	A	0.0062	2.7033	0.0649	2.3662		
Red Maple	*Acer rubrum*	Young et al. 1980	A	0.0223	2.2055	0.0787	2.4898		
Silver Maple	*Acer saccharinum*	Young et al. 1980	A	0.0223	2.2055	0.0787	2.4898		
Sugar Maple	*Acer saccharum*	Young et al. 1980	A	0.0104	2.5515	0.1626	2.2894		
Mountain Maple	*Acer spicatum*	Young et al. 1980	A	0.0223	2.2055	0.0787	2.4898		
Serviceberry	*Amelanchier sp.*	Smith and Brand 1983	C	0.036855	2.887	0.005425	2.111		
Yellow Birch	*Betula alleghaniensis*	Ter-Mikaelian and Korzukhin 1997	A	0.0113	2.7995	0.1383	2.2683		
River Birch	*Betula nigra*	Hocker and Earley 1983	A	0.0215	2.5	0.2044	2.17		
Paper Birch	*Betula papyrifera*	Hocker and Earley 1983	A	0.0215	2.5	0.2044	2.17		
Dogwood	*Cornus sp*	Smith and Brand 1983	C	0.039646	2.575	0.00945	1.762		
Hazelnut	*Corylus sp*	Smith and Brand 1983	C	0.039646	2.575	0.00945	1.762		
White Ash	*Fraxinus americana*	Ker 1980, 1984	A	0.0315	2.1955	0.1124	2.3649		
Black Ash	*Fraxinus nigra*	Ter-Mikaelian and Korzukhin 1997	B	0.0315	2.1955	0.0275	2.1002	0.0926	2.3879
Green Ash	*Fraxinus pennsylvanica*	Ker 1980, 1984	A	0.0315	2.1955	0.1124	2.3649		
Winterberry	*Ilex sp*	Smith and Brand 1983	C	0.055497	3.34	0.010747	2.831		
Ironwood	*Ostrya virginiana*	Hocker and Earley 1983	A	0.0215	2.5	0.2044	2.17		
Bigtooth Aspen	*Populus grandidentata*	Perala and Alban 1994	B	0.1368	1.751	0.0333	2.2142	0.0426	2.5618
Quaking Aspen	*Populus tremuloides*	Ruark etal 1987	B	0.0065	2.695	0.0108	2.532	0.0407	2.606
Quaking Aspen	*Populus tremuloides*	Pastor and Bockheim 1981	B	0.0038	2.695	0.0437	2.146	0.1714	2.199
Pin Cherry	*Prunus pensylvanica*	Young et al. 1980	A	0.0406	1.9197	0.0951	2.2988		
Black Cherry	*Prunus serotina*	Young et al. 1980	A	0.0716	2.6174	-0.0203	2.018		
Willow	*Salix sp*	Smith and Brand 1983	C	0.027194	2.762	0.006411	2.066		
Mountain Ash	*Sorbus sp*	Smith and Brand 1983	C	0.02659	2.881	0.004468	2.581		
Basswood	*Tilia americana*	Ter-Mikaelian and Korzukhin 1997	A	0.0389	1.84	0.073	2.29		
American Elm	*Ulmus americana*	Ter-Mikaelian and Korzukhin 1997	C	0.0825	2.468	0.0062	1.933		
Rock Elm	*Ulmus thomasii*	Ter-Mikaelian and Korzukhin 1997	C	0.0825	2.468	0.0062	1.933		

Model A: AGB = Branches + Stem = $a\,[\text{DBH}]^b + c[\text{DBH}]^d$ Bark is included in equation.
Model B: AGB = Branches + Bark + Wood = $a[\text{DBH}]^b + c[\text{DBH}]^d + e[\text{DBH}]^f$
Model C: AGB = Total aboveground biomass - Foliage = $a[\text{DBH}]^b - c[\text{DBH}]^d$

Table 1. Strength of relationship between LiDAR metrics and aboveground biomass from selected recent studies. Note that the types of LiDAR systems used, the metrics derived, and the definition of aboveground biomass vary in these studies.

Study	Location	Vegetation Type	R^2
Means *et al.* 1999	Western Oregon	Fir/Hemlock Coniferous Forest	0.90 - 0.96
Popescu *et al.* 2004	Virginia	Pines, Mixed hardwoods	Pines: 0.82 Deciduous: 0.33
Hall *et al.* 2005	Colorado front range	Ponderosa Pine	0.74 - 0.79
Lefsky *et al.* 2005	Washington and Oregon	Fir/Hemlock/Spruce/Pine Several sites with varying species compositions, primarily conifer-dominated.	0.92
Lefsky *et al.* 2002	Oregon, Maryland, Manitoba	Fir/Hemlock, Mixed Deciduous, Boreal Black Spruce	0.84
Patenause *et al.* 2004	UK	Mixed Hardwoods	0.55-0.72*
Nelson *et al.* 2003	Delaware	Mixed Hardwoods and Conifers. Profiling LiDAR sampled entire state	0.58-0.71
Lim *et al.* 2003	Ontario	Sugar Maple, Yellow Birch	0.85

*Patenaude *et al.* present their results in units of carbon, rather than biomass, and present correlation coefficients (r) rather than of coefficients of determination (R^2). I have squared their reported values in this table. They reported r = .74 at the plot scale and r=.85 at the stand scale.