Testing the value of high resolution LiDAR data for assessing the structure and integrity of forest canopies that influence tree health, insect populations, and bird habitats.

Principal Investigator: Allan M. Strong

Affiliation/Institution: The University of Vermont

Email: Allan.Strong@uvm.edu

Mailing address: Aiken Center, 81 Carrigan Drive, Burlington, VT 05405

Co-Principal Investigators: Paul G. Schaberg[1], Gary J. Hawley[2], & Jarlath O'Neil-Dunne[2]

Affiliations/Institutions: [1]USDA Forest Service, [2]The University of Vermont

Emails: pschaberg@fs.fed.us, Gary.Hawley@uvm.edu, Jarlath.Oneil-Dunne@uvm.edu

Graduate Student: Christopher F. Hansen[2], Christopher.Hansen@uvm.edu

Collaborators and Affiliations: John Battles, University of California, Berkeley, jbattles@berkeley.edu, Shelly A. Rayback[2], Shelly.Rayback@uvm.edu, Sean W. MacFaden[2], Sean.MacFaden@uvm.edu, Nicholas Rodenhouse, Wellesley College, nrodenho@wellesley.edu

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Key Results:

- High-resolution LiDAR is a robust remote sensing tool that can accurately model forest canopy vertical structure. Additionally, LiDAR corresponds with some measures of forest health and productivity and arthropod and bird abundance and diversity but not others.
- However, LiDAR's accuracy is dependent on the congruity of spatial scales between LiDAR and ground based metrics, as well as the method used to classify the raw LiDAR data into meaningful structural categories.

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http://www.nsrcforest.org

Project Summary

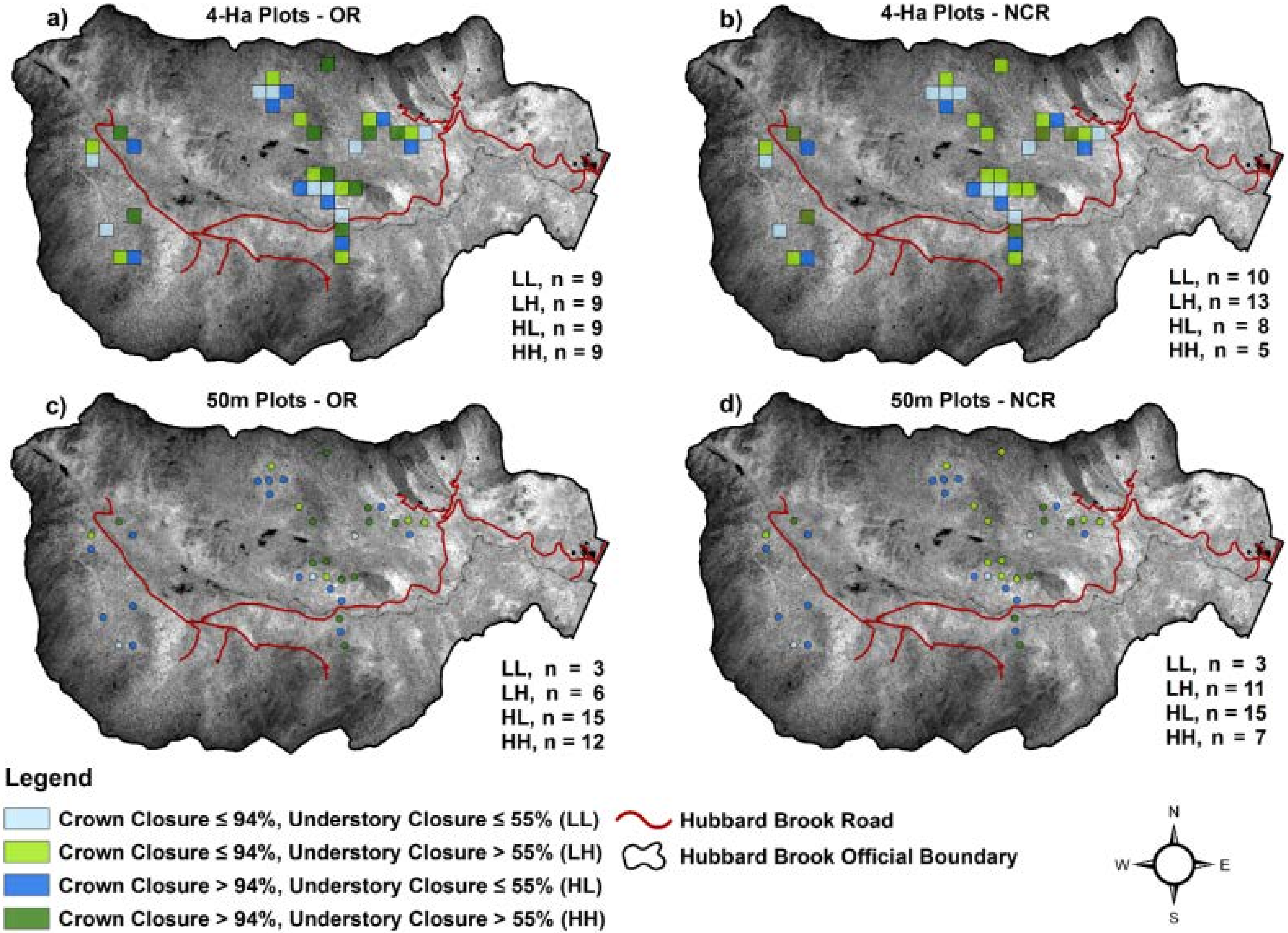
- Rationale: Light Detection and Ranging (LiDAR) is an active remote sensing technique that directs pulses of light from an aerial sensor to the earth's surface and records the timing and intensity of reflected pulses back to the sensor. The resulting LiDAR point cloud shows great promise in representing three dimensional canopy structure and complexity (Lefsky et al. 2002). High-resolution LiDAR data have not been used to assess arthropod and bird diversity and abundance despite spatial distributions of ecological parameters (i.e., variations in vegetation structure and composition) being fundamental in explaining patterns of biodiversity (MacArthur and MacArthur 1961, MacArthur and Horn 1969). In addition, the use of LiDAR data to remotely assess crown features that relate more directly to forest health and productivity (e.g., crown density, vigor and dieback) is uncommon but shows promise (Reutebuch et al. 2005).
- Methods: High-resolution LiDAR data (flown summer 2009) were acquired for the Hubbard Brook Experimental Forest (HBEF) in New Hampshire. LiDAR data were classified into four canopy structural categories. Ground-based measures of forest canopy structure (e.g., percent crown and understory closure, basal area, etc.), forest health and productivity (e.g., xylem increment growth, foliar nutrition, vigor and dieback, etc.), and arthropod and bird diversity and abundance (via canopy branch clippings and standard point counts, respectively) were collected on 36, 50m-radius plots throughout HBEF during summer of 2012. Statistical analyses were used to assess the relationships between LiDAR categories of forest canopy structure and ground based measures of forest structure, forest health and productivity, and arthropod and bird abundance and diversity.
- Major findings: High-resolution LiDAR is a robust remote sensing tool that can accurately model forest canopy vertical structure. Additionally, LiDAR corresponds with some measures of forest health and productivity and arthropod and bird abundance and diversity but not others. However, LiDAR's accuracy is dependent on the congruity of spatial scales between LiDAR and ground based metrics, as well as the method used to classify the raw LiDAR data into meaningful structural categories.
- Implications for the region: Results from this study have shown that high-resolution LiDAR data are useful in assessing forest structure, as well as biotic and abiotic components of the forest. The above methods were applied to the HBEF, however, they could easily be applied to other areas of the northeastern forest to help quantify, conserve and manage biodiversity.

Background and Justification

Ecological studies have suggested that the spatial distributions of fundamental ecological parameters, including variations in vegetation structure and composition, are central in explaining patterns of biodiversity (MacArthur and MacArthur 1961, MacArthur and Horn 1969). In particular, forest canopies are important sources of nutrient and water uptake, and are drivers of net primary production that support and influence higher trophic levels. Quantifying the vertical structure and complexity of forest canopies has traditionally been limited in spatial extent, as well as limited to expensive and labor-intensive field based data collection (Lefsky et al. 2002, Vierling et al. 2008). Passive remote sensing techniques that are useful for assessing canopy structure and complexity at larger spatial scales have been limited by their two-dimensional nature (Lefsky et al. 2002, Koukoulas and Blackburn 2004, Vierling et al. 2008). Due to these limitations, and especially at larger spatial scales, canopy structure and complexity have not been fully analyzed and integrated as modulators of biodiversity. Recent advances in LiDAR have provided a new source of geospatial data that provides detailed information of the 3-D structure of forest canopies (Vierling et al. 2008). Coarse-scale LiDAR has already been used to estimate the vertical distribution and complexity of canopies in deciduous hardwood forests and relate these to one important indicator of biodiversity: bird species richness (Goetz et al. 2007, Goetz et al. 2010). However, improvements in habitat analysis and prediction afforded by the use of high-resolution LiDAR data have not been fully evaluated. In addition, the use of LiDAR data to remotely assess crown features that relate more directly to forest health and productivity (e.g., crown density, vigor and dieback) is uncommon but shows promise (Reutebuch et al. 2005).

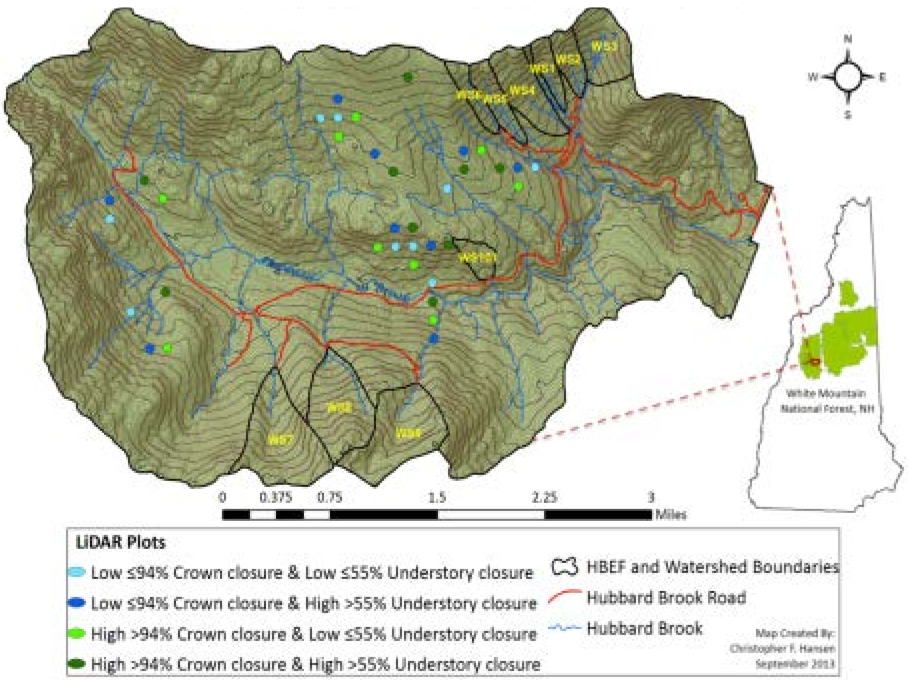
Methods

LiDAR Classification Schemes

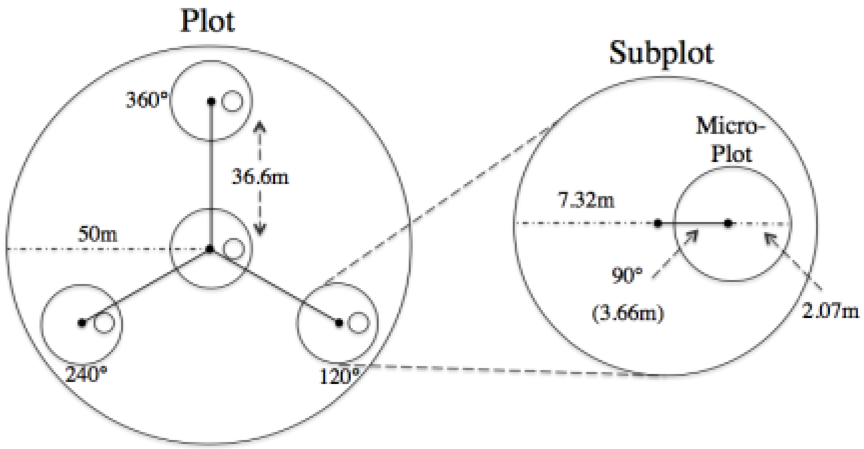


HBEF LiDAR classification schemes: a) 4-Ha plots and original classification routine (OR), b) 4-Ha plots with no crown refinement (NCR), c) 50m plots and original classification routine, and d) 50m plots with no crown refinement.

Study Site:
Hubbard Brook Experimental Forest
West Thornton, NH



Plot Design:
Forest Inventory and Analysis (FIA) Protocol



Methods

LiDAR Ground Truthing

- % Crown and Understory Closure
- Basal Area

Abiotic Measures

- Temperature and Relative Humidity
- Soil Moisture



Methods

Forest Health and Productivity

- Yellow birch and sugar maple
- Dominant and co-dominant
- 5-trees per species per plot

- Foliage Samples
- Crown Vigor and Dieback
- Xylem Increment Cores
  - 2-cores per tree
  - Annual increment measured
  - Growth assessed as basal area increment (BAI)






Methods

Arthropod Abundance and Diversity

- Branch Clippings - Max Height of 10 meters
- Two Trees Per Species (Yellow Birch & Sugar Maple) Per Plot
- Arthropods Counted and Identified to Order

Bird Abundance and Diversity

- 50m – Fixed Radius Point Counts
- Ten Minute Surveys – Three 3-Min 20-Sec Intervals
- Two Observers Visited Each Plot Twice

Significant Results Overview

Plot means were calculated for all ground-based measures and an analysis of variance (ANOVA) was used for each measure to assess its relationships to the LiDAR categories. Significant results were found in the follow measures in at least one of the classification schemes:

LiDAR Ground Truthing

- % Crown Closure
- % Understory Closure
- Basal Area (m^2/Ha)

Abiotic Measures

- Volumetric Soil Moisture (%)
- Temperature (^oF)
- Relative Humidity (%)

Forest Health & Productivity

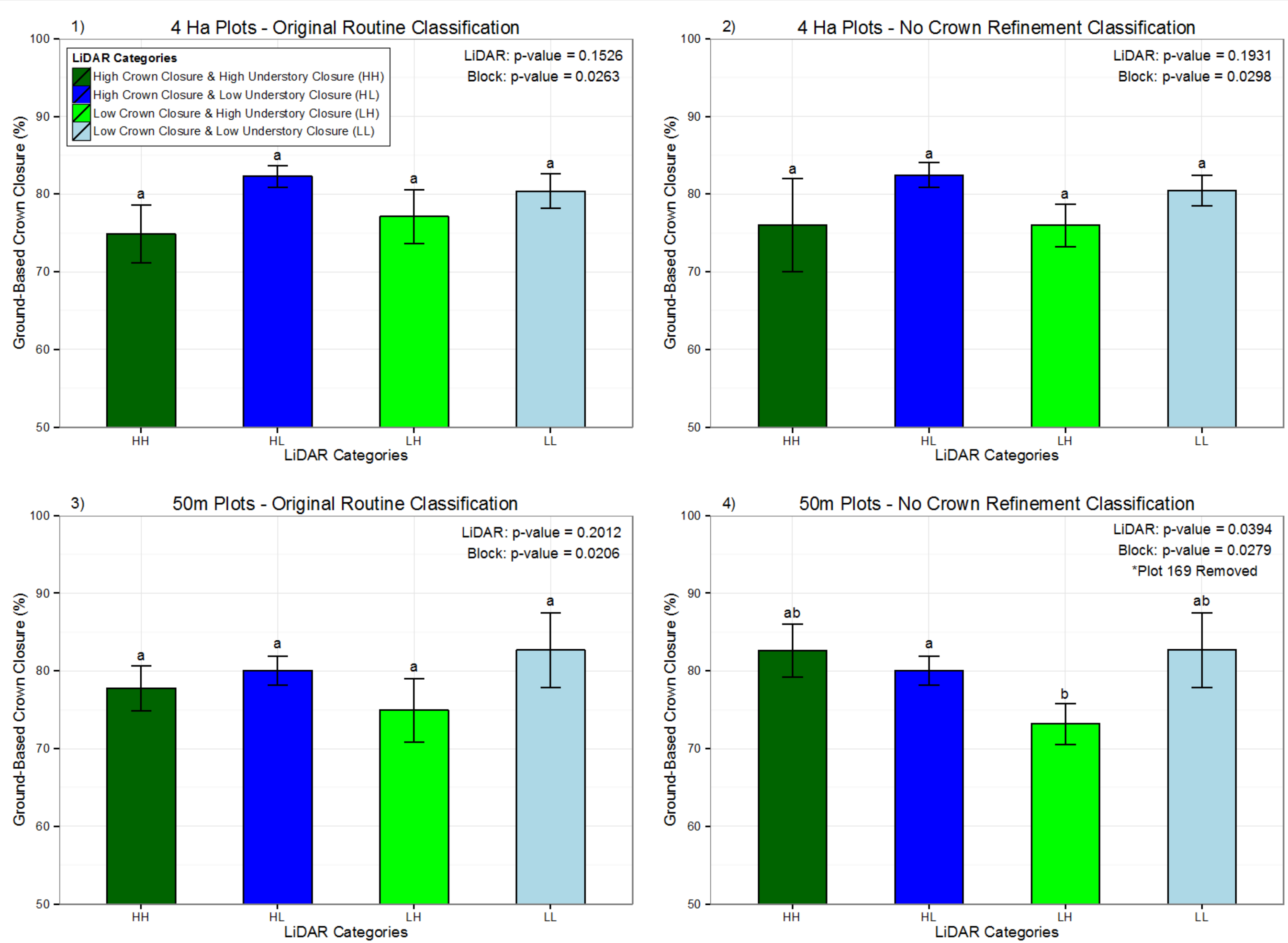
- Crown Vigor (1-4 scale) & Dieback (0-100%)
- Foliar Nutrition (mg kg^{-1})
- Xylem Increment Growth (BAI – cm^2)

Bird Abundance and Diversity

- Shannon-Wiener Diversity Index
- Ecological Species Diversity Index

Results/Project Outcomes - LiDAR Ground Truthing

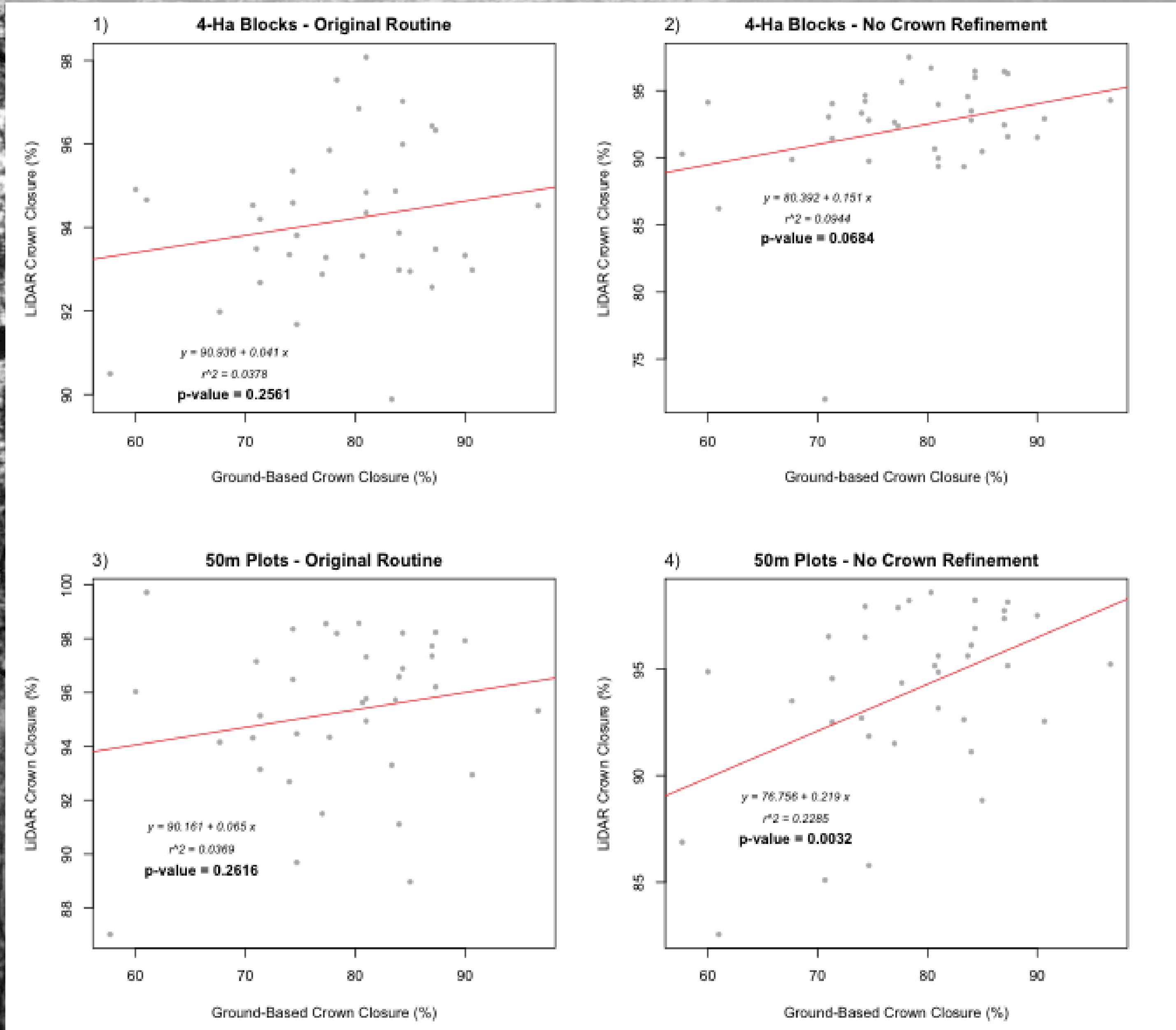
Ground-based Crown Closure



Means (±1S.E.) for ground-based crown closure by LiDAR category and for different classification schemes. Means without common letters differed significantly at $P \leq 0.05$ based on ANOVA tests.

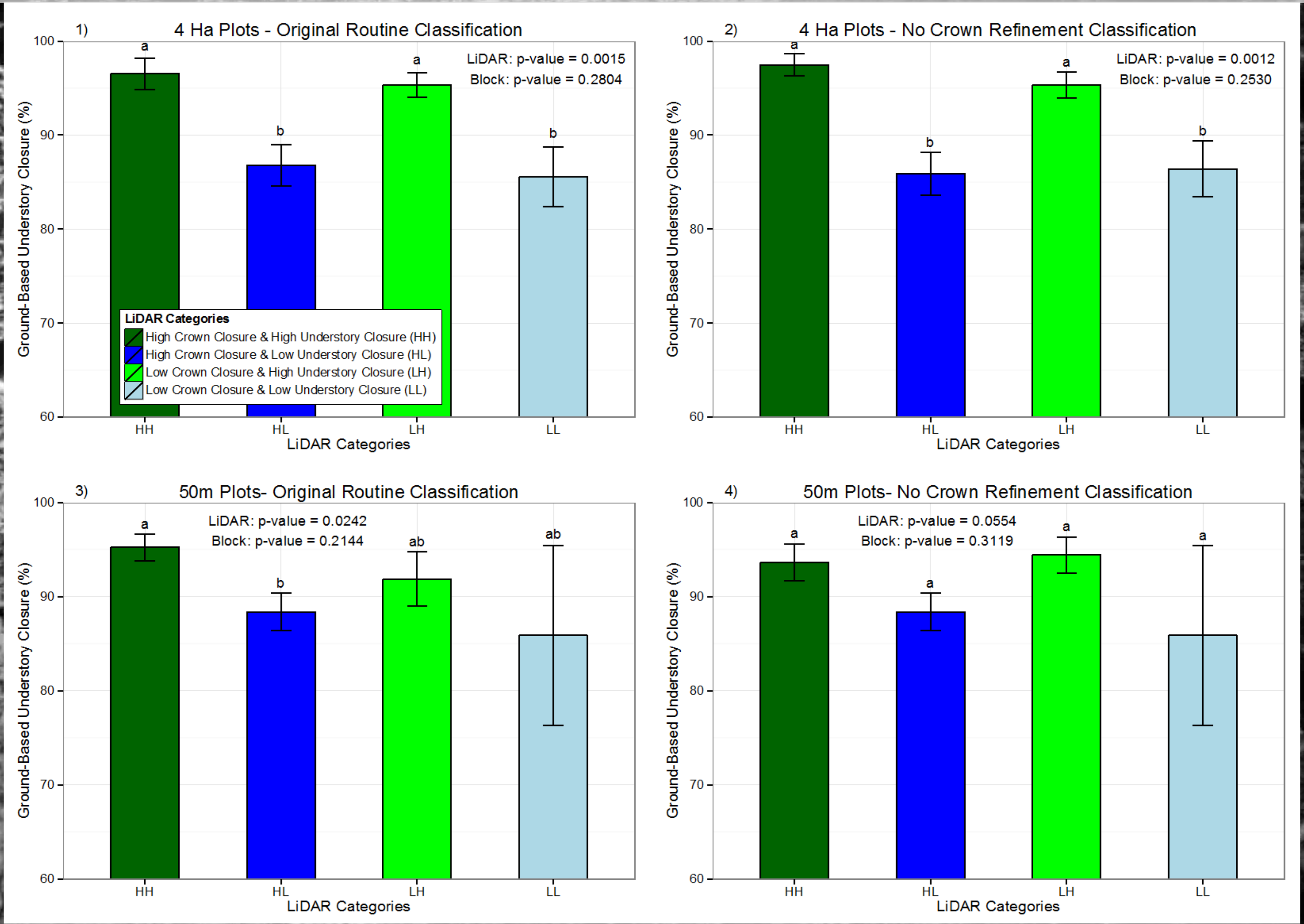
Results/Project Outcomes - LiDAR Ground Truthing

LiDAR Continuous Crown Closure & Ground-based Crown Closure



Results/Project Outcomes - LiDAR Ground Truthing

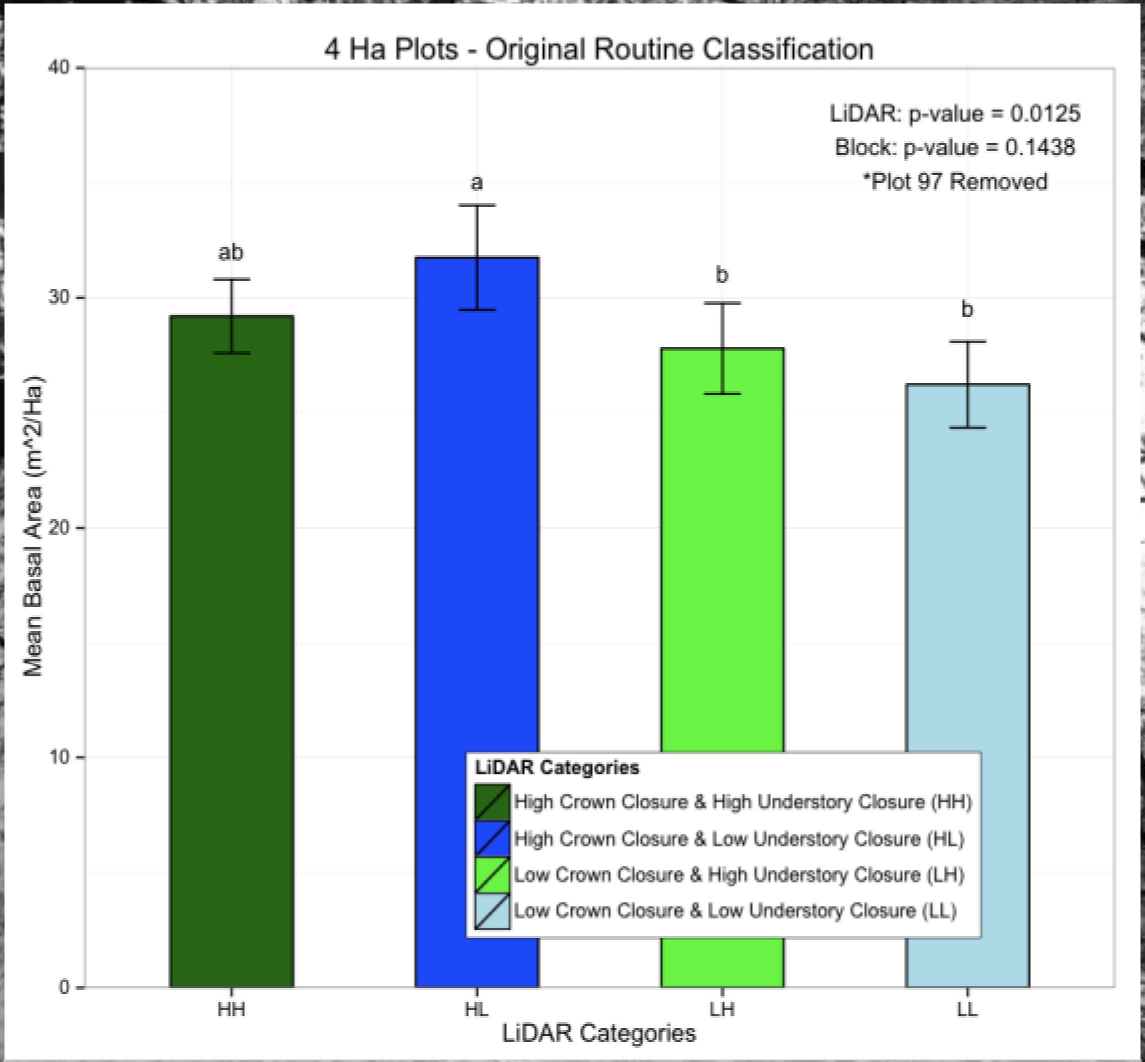
Ground-based Understory Closure



Means (±1S.E.) of ground-based understory closure by LiDAR category and for different classification schemes. Means without common letters differed significantly at $P \leq 0.05$ based on ANOVA tests.

Results/Project Outcomes – LiDAR Ground Truthing

Mean Basal Area (m^2/Ha) for Dominant, Co-dominant & Intermediate Trees



Means (±1S.E.) of basal area (m^2/Ha) by LiDAR category for HBEF plots. Means without common letters differed significantly at $P \leq 0.05$ based on ANOVA tests.

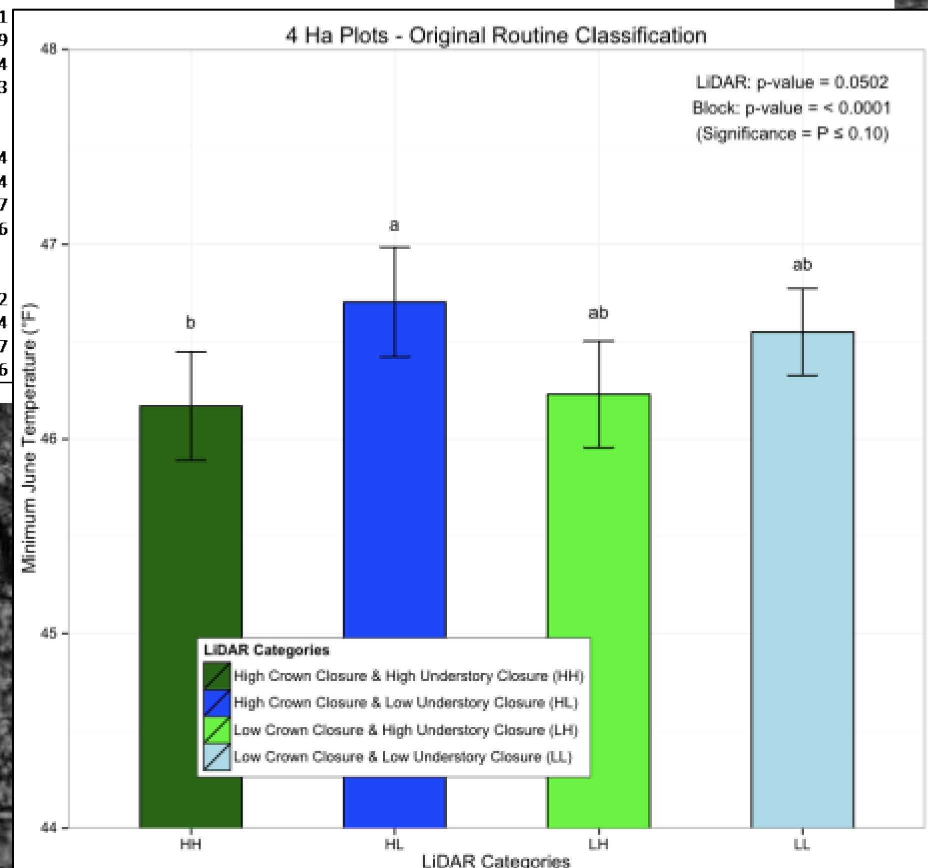
Significantly greater basal area on plots with greater crown closure, as modeled by LiDAR

Results/Project Outcomes – Abiotic Measures

Minimum June Temperature

Daily mean minimum (± 1SE) temperatures for June, July, August, and September at HBEF LiDAR plots. Significant differences between LiDAR categories based on ANOVA are indicated by asterisks: *, *P < 0.10*; and **, *P < 0.05*.

LiDAR Classification	Mean Temperature (°F)				Min Temperature (°F)				Max Temperature (°F)			
& Category	June	July	August	Sept.	June	July	August	Sept.	June	July	August	Sept.
4-Ha Plots - OR												
HH (n=9)	63.12 ± 0.25	64.64 ± 0.26	64.16 ± 0.26	54.39 ± 0.23	46.17 ± 0.28*	49.69 ± 0.77	48.25 ± 0.48	38.13 ± 0.60	83.18 ± 0.32	80.37 ± 0.27	79.84 ± 0.33	72.64 ± 0.31
HL (n=9)	63.32 ± 0.27	64.92 ± 0.24	64.41 ± 0.23	54.72 ± 0.22	46.70 ± 0.28*	49.81 ± 0.56	49.10 ± 0.38	38.46 ± 0.47	82.92 ± 0.42	80.39 ± 0.35	80.16 ± 0.28	73.44 ± 0.78
LH (n=9)	63.25 ± 0.33	64.87 ± 0.32	64.36 ± 0.31	54.57 ± 0.29	46.23 ± 0.27*	50.54 ± 0.49	48.96 ± 0.39	39.04 ± 0.37	82.55 ± 0.59	80.24 ± 0.54	79.80 ± 0.55	72.20 ± 0.68
LL (n=9)	63.21 ± 0.30	64.88 ± 0.29	64.42 ± 0.29	54.71 ± 0.29	46.55 ± 0.22*	49.85 ± 0.67	49.06 ± 0.56	38.56 ± 0.55	83.53 ± 0.59	80.87 ± 0.61	79.95 ± 0.48	74.06 ± 1.58
4-Ha Plots - NCR												
HH (n=5)	63.31 ± 0.20	64.63 ± 0.26	64.06 ± 0.25	54.28 ± 0.24	46.42 ± 0.29**	48.51						
HL (n=8)	63.45 ± 0.27	65.02 ± 0.24	64.48 ± 0.25	54.77 ±0.24	46.79 ± 0.31**	49.69						
LH (n=13)	63.13 ± 0.27	64.81 ± 0.26	64.33 ± 0.26	54.56 ± 0.24	46.12 ± 0.24**	50.74						
LL (n=10)	63.11 ± 0.29	64.81 ± 0.27	64.36 ± 0.27	54.68 ± 0.26	46.50 ± 0.21**	49.93						
50m Plots - OR												
HH (n=12)	63.34 ± 0.22	64.94 ± 0.24	64.46 ± 0.24	54.67 ± 0.22	46.37 ± 0.23**	50.24						
HL (n=15)	63.10 ± 0.20	64.70 ± 0.17	64.19 ± 0.16	54.48 ± 0.15	46.49 ± 0.19**	49.54						
LH (n=6)	63.33 ± 0.49	64.92 ± 0.46	64.44 ± 0.42	54.74 ± 0.36	46.52 ± 0.36**	50.67						
LL (n=3)	63.16 ± 0.50	64.88 ± 0.62	64.38 ± 0.75	54.64 ± 0.85	45.98 ± 0.69**	49.66						
50m Plots - NCR												
HH (n=7)	63.50 ± 0.19	64.96 ± 0.26	64.41 ± 0.26	54.58 ± 0.24	46.61 ± 0.16**	49.62						
HL (n=15)	63.10 ± 0.20	64.70 ± 0.17	64.19 ± 0.16	54.48 ± 0.15	46.49 ± 0.19**	49.54						
LH (n=11)	63.23 ± 0.33	64.91 ± 0.32	64.48 ± 0.30	54.77 ± 0.27	46.30 ± 0.29**	50.87						
LL (n=3)	63.16 ± 0.50	64.88 ± 0.62	64.38 ± 0.75	54.64 ± 0.85	45.98 ± 0.69**	49.66						

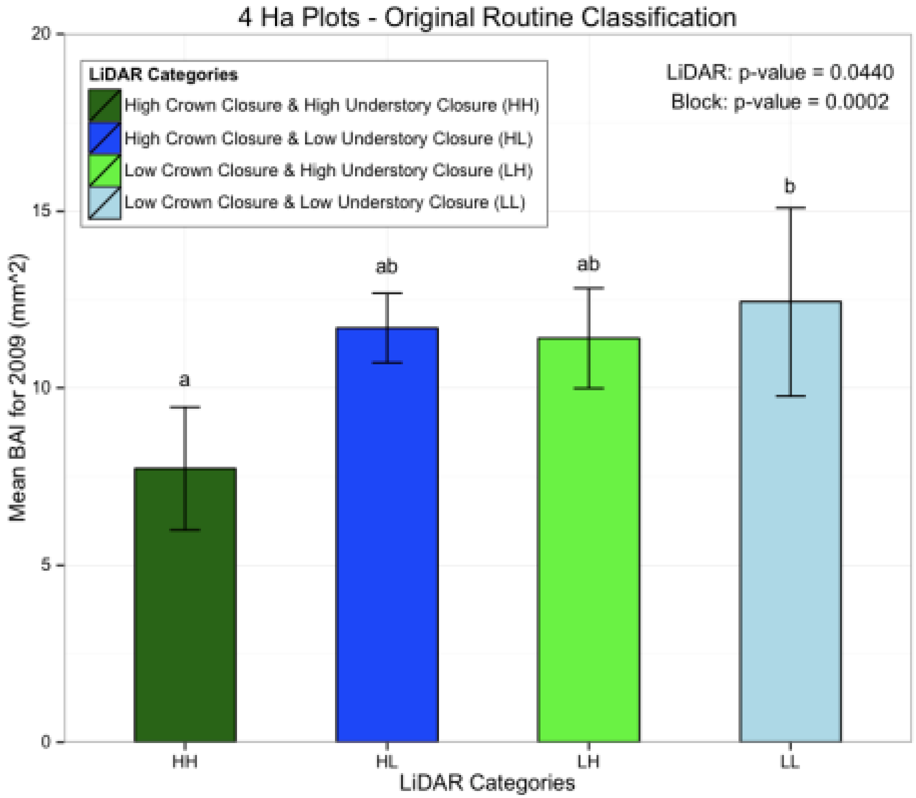


Significantly higher minimum June temperatures on plots with lower LiDAR understory closure

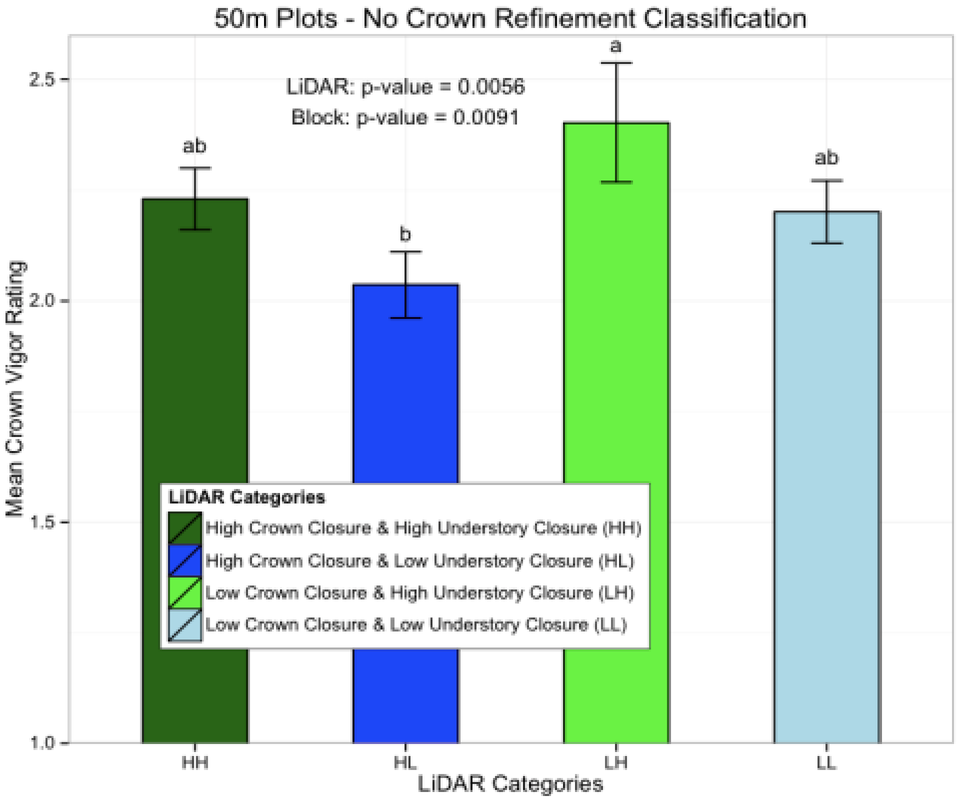
Results/Project Outcomes – Forest Health & Productivity

Mean 2009 BAI & Mean Crown Vigor Rating

Mean 2009 BAI



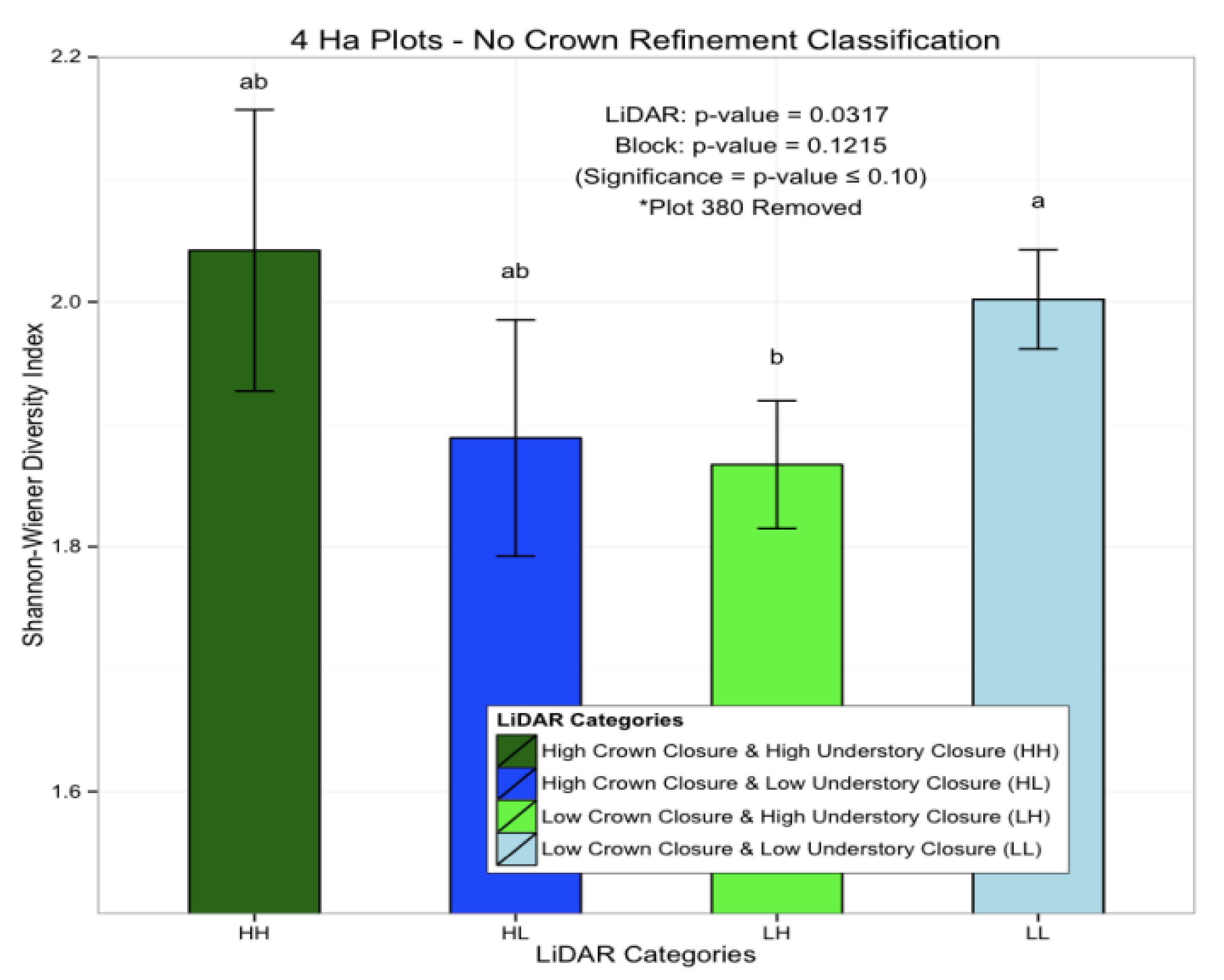
Mean Crown Vigor Rating



Means (±1S.E.) of 2009 BAI & crown vigor ratings by LiDAR category for HBEF plots. Means without common letters differed significantly at $P \leq 0.05$ based on ANOVA tests.

Results/Project Outcomes – Bird Diversity

Shannon-Wiener Diversity Index



Means (±1S.E.) of Shannon-Wiener Diversity Index by LiDAR category for HBEF plots. Means without common letters differed significantly at $P \leq 0.05$ based on ANOVA tests.

Implications and Applications in the Northern Forest Region

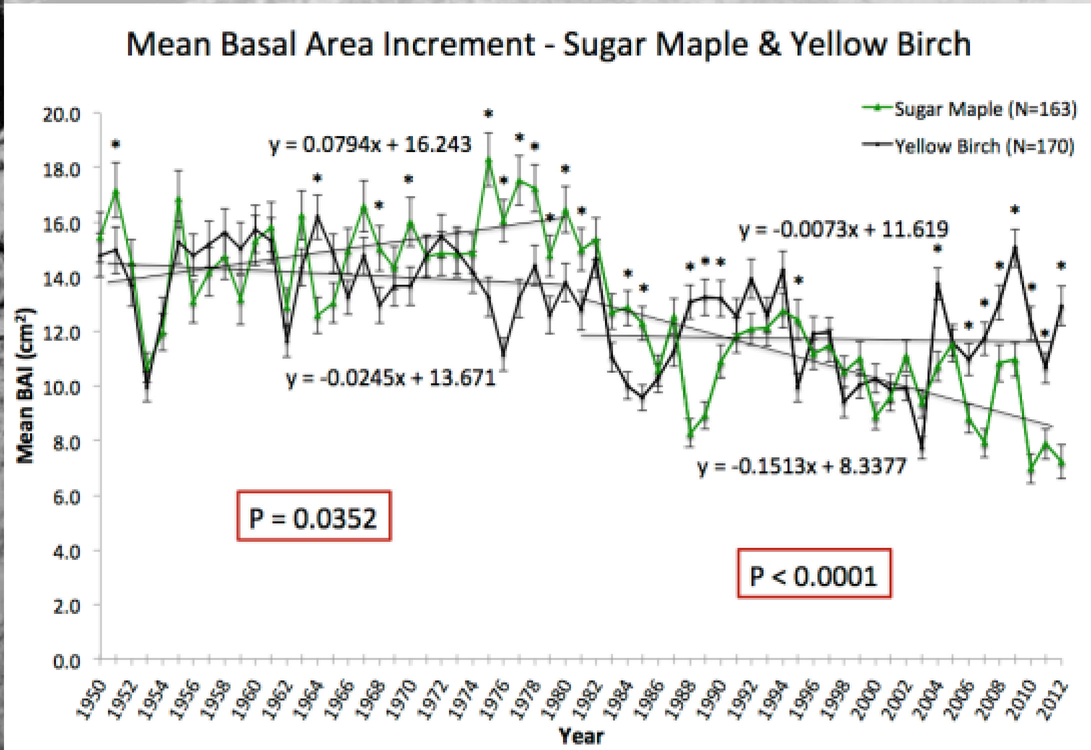
- Within the northern forest region there are many anthropogenic factors (e.g., acidic deposition, climate change, and non-native invasive pests) that will likely change the forest structure and composition over time. In response to this, forest and wildlife professionals need cost effective means to manage and conserve the northern forest.
- High-resolution LiDAR data are becoming increasing more available and cost effective, with some states now having complete coverage. Results like the ones presented here, could be extrapolated to broader areas with similar objectives addressed.
- With further validation and more refined methodology, high-resolution LiDAR data can be used to help manage and conserve biodiversity across the northern forest region. This is especially true considering that LiDAR can accurately model forest structure, which is fundamental to forest health and productivity and arthropod and bird abundance and diversity, across landscape scales as compared to traditionally remotely sensed data (i.e., two-dimensional remote sensing data).

Future directions

- Next steps of this research will include continuing to explore/interpret the results from this study. Some results are straightforward and easily interpreted, whereas others are not (e.g., LiDAR's relationship to bird diversity via Shannon-Wiener's Diversity Index)
- Scale and/or classification scheme played an important role in LiDAR's relationship to many of the response variables. Future directions of this research include looking at different ways to summarize and test the LiDAR against ground-based metrics (e.g., looking at the density of points in the raw LiDAR point cloud as a measure of canopy vertical structure as oppose to the percent understory closure as calculated from the 0.5-10m AGL surface model).
- Future directions will also include using structural equation modeling (SEM), also known as pathway analysis (Grace and Pugesek 1998, Garson 2008), to assess relationships between abiotic environmental factors, forest structure, forest health and productivity, and arthropod and bird abundance and diversity measures regardless of LiDAR categories.

Future directions

- Large datasets of forest health and productivity and arthropod and bird abundance and diversity were collected for this project. Regardless of their relationship to LiDAR, they could provide valuable information about ecosystem functioning and trophic interactions within the broader northern forest, especially in the context of global climate change. Analyses of sugar maple and yellow birch growth using the xylem increment cores and their crown vigor status, have already begun.



- Previous research has shown increased yellow birch and decreased sugar maple growth at HBEF (van Doorn et al. 2011). Xylem increment cores and foliar nutrition data could help evaluate the nature and timing of recent changes in the growth of these species.

List of Products

Presentations at Scientific Conferences:

- Hansen, C.F., P.G. Schaberg, G.H. Hawley, S.A. Rayback. 2013. Preliminary analysis of valley-wide growth trends for sugar maple (*Acer saccharum*) and yellow birch (*Betula alleghaniensis*) trees. Presentation at the HubbardEcosystem Study 50th Annual Cooperator's Meeting, West Thornton, NH, July 10th, 2013.
- Hansen, C.F., P.G. Schaberg, G.H. Hawley, S.A. Rayback, S.W. MacFaden. 2014. LiDAR remote sensing of forest canopy structure and its relationship to forest health and productivity and arthropod and bird diversity in a northern hardwood forest. Abstract submitted and accepted for presentation at the Hubbard Brook Ecosystem Study 51st Annual Cooperator's Meeting, West Thornton, NH, July 9th, 2014.
- Hansen, C.F., P.G. Schaberg, S. A. Rayback, G.H. Hawley, A.M. Strong, S.W. MacFaden. 2014. LiDAR remote sensing of forest canopy structure and its relationship to forest health and productivity in a northern hardwood forest. Abstract submitted and accepted for presentation at the 99th Ecological Society of America annual meeting, Sacremento, CA, August 14th, 2014

Thesis:

- Hansen, C.F. In preparation. LiDAR remote sensing of forest canopy structure and its relationship to the abiotic and biotic components of a northern hardwood forest. M.S. Thesis, expected data: September 2014.

Tangible Products:

- High-resolution LiDAR surface models: 1m resolution digital elevation model (DEM), 1m resolution normalized digital surface model (nDSM), and 1m resolution 0.5-10m above ground level (AGL) surface model

Questions?

Please contact:

Allan M. Strong (Allan.Strong@uvm.edu)
or
Christopher F. Hansen (Christopher.Hansen@uvm.edu)