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Estimating aboveground biomass in the boreal forests of the Yukon River Basin, Alaska

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I. Introduction

Boreal forest biome is the second biggest terrestrial ecosystem, which encompasses 33% of the forest area and holds 23% of total carbon stores on the earth's land surface. Quantification of aboveground biomass (AGB) in Alaska's boreal forests is essential to accurately evaluate terrestrial carbon stocks and dynamics in northern high-latitude ecosystems. However, regional AGB datasets with spatially detailed information (<500 m) are not available for this extensive and remote area.

The objective in this study is to map AGB at 30-m resolution for the boreal forests in the Yukon River Basin of Alaska using recent Landsat data and ground measurements. An accurate estimation of the regional AGB will provide an important data input for ecological modeling in this region.

II. Study Area

The Yukon River Basin is located in central Alaska and northwestern Canada, is the 5th largest basin in North America, which has a drainage area of about 509,000 km^2 (Figure 1). According to the 2001 National Land Cover Database (NLCD 2001), the major land cover types are evergreen forest (28.4%), deciduous forest (7.1%), mixed forest (5.9%), shrubs/scrubs (28.6%), dwarf shrub (8.6%), woody wetlands (7.3%), and emergent herbaceous wetlands (2.5%). Wildfires are also very common within the region.

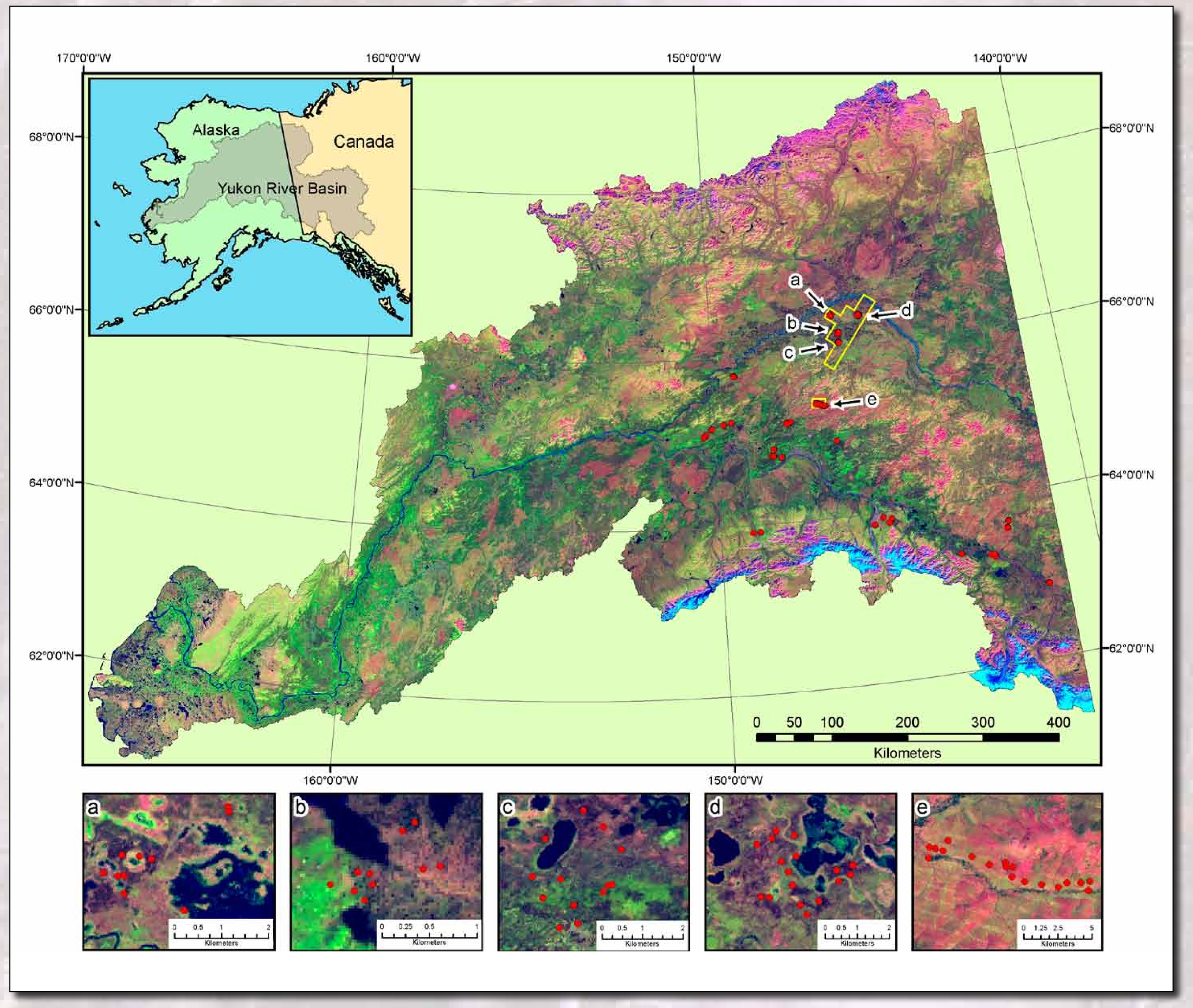

Figure 1. The Map of the Yukon River Basin of Alaska. The Landsat ETM+ image showing in the map is a three-year (2008 - 2010) composite derived from WELD data. The two yellow polygons outline the airborne lidar extents. Red solid circles in the main map and the inserts indicate the field sampling sites.

III. Data

1. Field measurements

We collected field data in the Yukon River Basin from 2008 to 2010 (Figure 1). Ground measurements included diameter at breast height (DBH) or basal diameter (BD) for live and dead trees and shrubs (>1 m tall), which were converted to plot-level AGB using allometric equations compiled for interior Alaska. The AGB measured in the field consisted of tree and shrub biomass and coarse woody debris (CWD) biomass.

2. Landsat TM data

We acquired Landsat Enhanced Thematic Mapper Plus (ETM+) images from the Web Enabled Landsat Data (WELD, http://landsat.usgs.gov/WELD.php) that provides multi-date composites of top-of-atmosphere reflectance and brightness temperature (BT). From the WELD images, we generated a three-year (2008 – 2010) image composite for the Yukon River Basin using a series of compositing criteria including non-saturation, non-cloudiness, maximum normalize difference vegetation index (NDVI), and maximum BT.

3. Airborne lidar data

Airborne lidar datasets were acquired for two sub-regions in the central basin in July and September, 2009 and October, 2010 (Figure 1). The data products were acquired with an aircraft-carried Optec ALTM Gemini system operated by Aero-Metric, Inc. The company processed the raw data and delivered the 2.5-m raster dataset of bare-earth digital surface model (DSM) and first-return DSM.

IV. Methods

1. Regression model development and regional AGB estimation

In this study, boreal forest AGB was defined as the sum of tree and shrub (live and dead) and CWD AGB. We used a regression method to estimate AGB based on the Landsat reflectance, BT, spectral indices, and field-measured AGB. In general, AGB demonstrated a logarithmic rate of increase against reflectance and spectral indices. To linearize this relationship, we transformed AGB to a natural logarithmic form. The final regression model was applied to the Landsat images to generate a map of boreal forest AGB for the Yukon River Basin.

2. Validation of the AGB models and maps

Because of the limited number of field plots, we applied 5-fold holdout cross-validation to evaluate the accuracies of the regression model and the AGB map. The mean absolute error (MAE) and the mean bias error (MBE) were used to compare the field-measured and model-estimated AGB values. We repeated the cross-validation 1,000 times. To further assess the accuracy of the AGB map, we used lidar images as an independent validation dataset. The vegetation height was calculated by the difference of the bare-earth DSM data and the first-return DSM data.

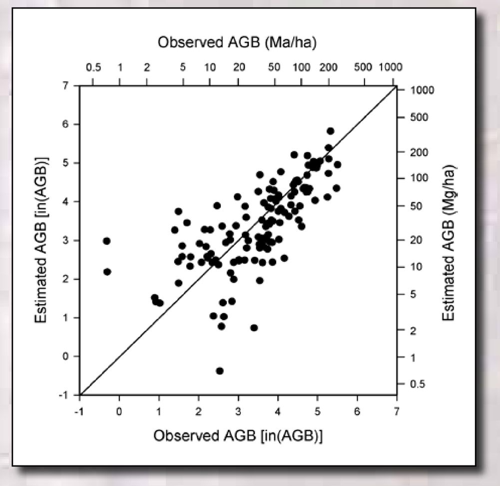

Figure 2. Agreement between the observed and estimated ln(AGB) values for the 133 samples used in model development.

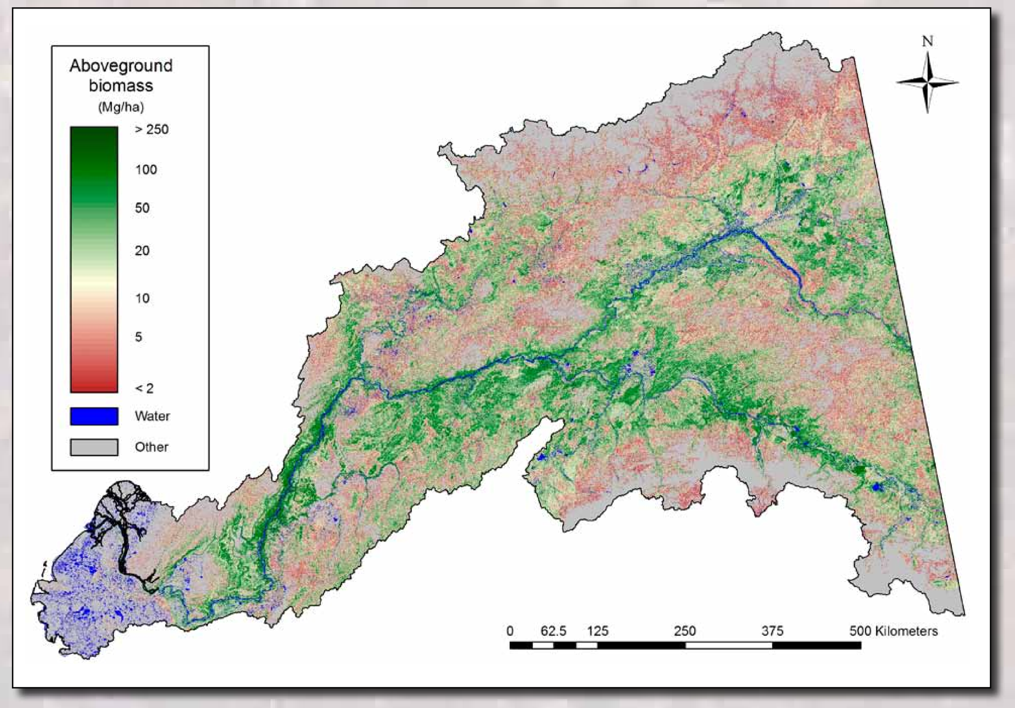

Figure 3. The map of boreal forest AGB at 30-m resolution for the Yukon River Basin, Alaska. The AGB was estimated based Landsat data and field measurements. NLCD 2001 was used to delineate forests and shrublands.

V. Results

1. Regression model and AGB estimation

The final regression model for the regional AGB estimation is

$$\ln(\mathrm{AGB}) = a + \sum_{i=1}^{11} b_i X_i$$

where, a and b_i are the regression coefficeints, X_i is the predictor variables including six reflectance bands, BT, NDVI, enhanced vegetation index (EVI), normalized difference infrared index (NDII), and normalized difference water index (NDWI). The model is significant (p-value < 0.0001) with R^2 = 0.656. Figure 2 illustrates the agreement between the observed AGB and model-predicted AGB (natural logarithmic transformed) for the 133 sampling sites. This model was applied to the Landsat image of the Yukon River Basin (Figure 1) for estimating the regional AGB (Figure 3). In the AGB map, water and other non-boeral forest areas were masked out using the NLCD 2001 data.

2. Accuracy assessment

We performed 5-fold holdout cross-validation for the 133 field plots used for developing the regression model and mapping AGB. The averaged MAE and MBE for 1,000 cross-validation runs are 32.8 Mg/ha and 2.1 Mg/ha, respectively. For the accuracy assessment with the lidar data, Figure 4 demonstrates the density scatterplots for the nonlinear relationships between estimated AGB and lidar-derived vegetation height. The mean and maximum heights, respectively, are the mean and maximum canopy heights derived from 2.5-m lidar data within a 30-m Landsat pixel. We created an exponential model for the relationship of AGB to mean and maximum heights: $\ln(AGB) = a + b(1\text{-}\exp[c(max)+d(mean)]$, where a, b, c, and d are the regression coefficients, max and $mean$ are maximum and mean canopy heights, respectively. The model was significant (p-value < 0.0001), with a pseudo-R^2 value of 0.385.

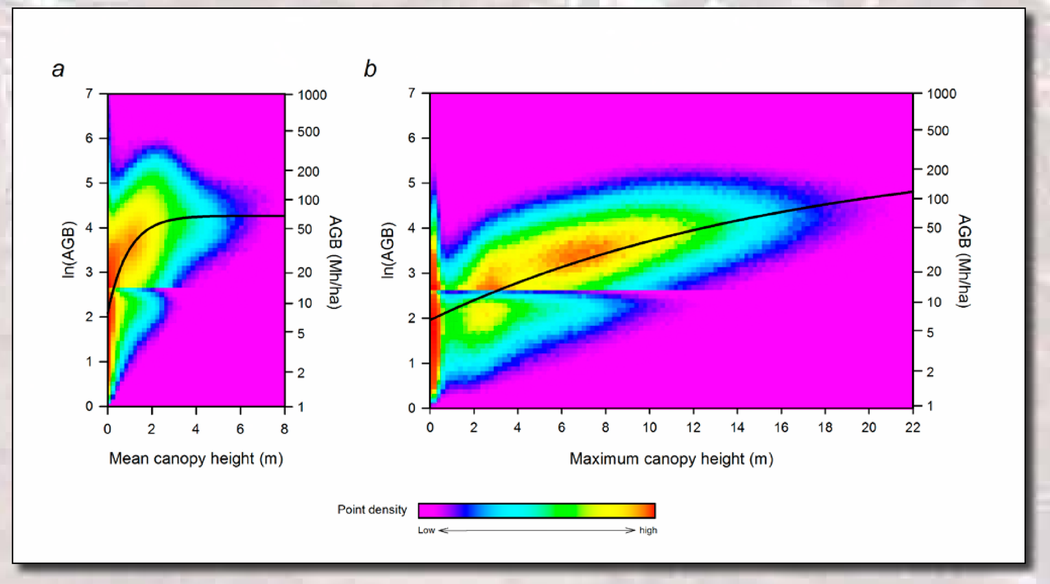

Figure 4. Density scatterplot of the AGB estimates verses lidar-derived mean (*a*) and maximum (*b*) canopy heights.

VI. Conclusions

We completed 30-m AGB mapping for the boreal forests in the Yukon River Basin of Alaska using Landsat data and field measurements including tree, shrub, and CWD. Accuracy assessment of the AGB map indicated that the MAE and MBE were 33 Mg/ha and 2 Mg/ha, respectively. The production of a basin-wide boreal forest AGB dataset will provide an important biophysical parameter for the modeling and investigation of Alaska's ecosystems.

Acknowledgments

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