ALLOMETRIC MODEL DEVELOPMENT IN LODGEPOLE PINE FORESTS OF THE GREATER YELLOWSTONE ECOSYSTEM

DANIEL B. TINKER ✦ RICK ARCANO
DEPARTMENT OF BOTANY ✦ UNIVERSITY OF WYOMING
LARAMIE

✦ INTRODUCTION

Changes in climatic patterns in western North America may modify natural fire regimes, resulting in alterations in forest structure and productivity (Amiro et al. 2000). More frequent fires would create substantial landscape-scale heterogeneity and, consequently, variability in how individual trees and stands allocate biomass in response to the differences in forest structure (Chapin et al. 2002; Turner et al. 2004). For example, in the lodgepole pine (*Pinus contorta* var. *latifolia* [Engelm. ex Wats.] Critchfield) forests of the Greater Yellowstone Ecosystem (GYE), recent and historic fires have created a complex mosaic of forest stand structures and aboveground net primary production (NPP) (Turner et al. 1997, 2004). The quantification of forest structure and function at large spatial scales requires accurate measurements of aboveground and belowground tree biomass.

Allometric equations for estimating above- and belowground biomass of lodgepole pine have been developed in Alberta, Canada, southeastern British Columbia, southeastern WY, and in Washington and Oregon (Johnstone 1971; Comeau and Kimmins 1989; Pearson et al. 1984; Gholz et al. (1979, respectively). More recently, allometric equations for young lodgepole pine saplings have also been developed in Yellowstone National Park (YNP) for aboveground biomass by Turner et al. (2004), and for belowground biomass by Litton et al. (2003). However, because of variability in latitude, growing conditions, substrate and climate, existing equations that predict biomass for mature lodgepole pine trees are not appropriate for use in the GYE, and new allometric equations specific for the GYE are needed. In this study, we will develop new allometric equations for predicting above- and belowground biomass in mature lodgepole pine forests of the GYE.

The specific objectives of this study were to: (1) develop allometric models for predicting above and belowground biomass of mature lodgepole pine trees in the GYE, and determine how these equations differ with stand density and age; (2) compare and contrast allometric equations developed in this study to allometric equations developed in other locations to determine applicability across geographic locations independent of forest structure.

✦ METHODS AND PROGRESS TOWARDS COMPLETION OF PROJECT

Study Area

The study area was within the GYE on the Caribou-Targhee National Forest (CTNF) bordering YNP. The GYE surrounds YNP and encompasses portions of three states in the western US: Wyoming, Idaho, and Montana. Elevations in YNP range from 1,620 m near Gardiner, Montana to 3,333 m in the Absaroka mountain range of Wyoming. Mean annual precipitation ranges from less than 28 cm yr^{-1} at lower elevations to about 180 cm yr^{-1} on the southwestern plateau (Knight 1994). Temperatures are cold during the winter, where high temperatures less than 0°C occur for an average of 87.6 days year, and summers are cool (Dirks and Martner 1982).

The dominant forest type is lodgepole pine forest, which occurs at middle elevations, but Spruce/ Fir (*Picea engelmanii /Abies lasiocarpa*) forests occur at higher elevations and Douglas-fir (*Pseudotsuga menziesii*) forests occur at lower elevations. Whitebark pine (*Pinus albicaulis*) dominates at the upper treeline, and Aspen (*Populus tremuloides*) occurs more commonly outside of YNP (Knight 1994).

✦ FIELD AND LAB METHODS

Allometric equations will be developed from trees in three lodgepole pine stands on the CTNF that represented two age classes and two density classes (Table 1). In the young (64 years old) age class, two stands of different densities were examined; one dense (YD) (2,452 trees/ha) and the other sparse (YS) (725 trees ha^{-1}). Because densities of lodgepole pine stands tend to converge as they get older (Kashian et al. 2005), a single sparse (674 trees ha^{-1}) stand was sampled in the older age class (OS) (164 years old).

Table 1. Sites for the development of allometric equations in the Greater Yellowstone Ecosystem.

Site Name	Elevation (m)	NAD 83, UTM Zone 12 Northing (m)	Easting (m)	Stand Age (years)	Stand Density (trees > 5cm DBH per hectare)	Stand basal area (m^2 per hectare)
Grassy Lake	2249	4886015	511735	165	674	16.84
Coffee Pot	1951	4926541	472232	64	725	19.71
US 20	1951	4925932	472657	64	2452	28.32

Although sites differed in density and age, they were located on similar soils. Elevations ranging from 1951 m to 2249 m were within the elevation range of lodgepole pine found for YNP. All sites were located at least 50 m from the road to facilitate equipment hauling and to avoid road influences.

All aboveground tree biomass totaling 46 trees was harvested during the summer of 2004 within the three stands, and 24 root systems were excavated to develop allometric equations where easily obtained morphological parameters, such as diameter at breast height, were tested as predictors of above-and belowground tree components. Fourteen trees were harvested in the YD stand and 15 trees were harvested in the YS stand; 17 were harvested in the OS stand. For belowground components, 5 root systems were excavated in both the YS and OS stands due to logistical difficulties associated with large root systems, while 14 root systems were harvested in the YD stand. Initially, we decided to harvest 15 trees in each stand. However, in the OS stand, three extra trees were harvested to ensure that all trees were within the proper age range, and one tree had to be removed because it was younger than the acceptable age range (150-165 years) for that stand. In addition, some field data for one tree in the YD stand was missing, and therefore, that tree was not included in the analyses.

Five trees were harvested along each of three 25m transects in each stand. Trees were generally selected at 5m intervals along each transect, but more importantly, trees were selected based on their diameter to represent the range of tree sizes found for trees in their respective stands. Trees were not chosen if they had any characteristics that would alter the biomass of the tree, such as heart rot or insect damage, major forking, crook or sweep, or any tree outside of the acceptable age range (≤15 years of the oldest tree in the stand).

Prior to harvest, DBH (diameter at breast height, 1.37m) and crown width were recorded. After felling of the tree, total height and height to crown base were measured. Crown base was defined as the point along the bole at the bottom of roughly 90% of the crown mass, and crown length was calculated as:

$$CL = H - HCB$$

(1) where CL = crown length, H = total tree height, and HCB = height to the base of the live crown.

<u>Aboveground Components</u>

Tree Bole - Each bole was harvested and all branches were removed. The bole was cut into three to four sections with 1 to 2 discs cut out as subsamples to determine moisture content for dry weight. For each bole, a disc was always taken at DBH and at 90% of crown base. Each bole section was weighed separately using a digital hanging scale (Salter-Brecknell). Discs were dried to a constant weight at 70°C in the lab to determine moisture content, and the dry: wet weight ratio for each disc was applied to determine dry weight of the entire bole section. For each DBH and crown base subsample, the following measurements were taken for determining sapwood area: phloem + bark thickness, total diameter, and heartwood diameter. Sapwood diameter can be determined by subtracting the diameter of phloem + bark and heartwood diameter from total diameter. Therefore, the following equation was used to determine sapwood area:

$$SA = a - b$$

(2) where SA = Sapwood Area, a = the basal area excluding phloem and bark, and b = heartwood area.

Branches - Branches were cut flush with the tree bole and were separated from foliage at 6.4 mm in diameter. Thus, branches consisted of all shoots minus the tree bole that were greater than 6.4 mm in diameter, because biomass smaller than 6.4 mm are likely to be consumed by fire (Despain 1990), allowing for post-fire estimates of branch biomass, independent of fine fuels that were likely to be consumed the fire. A subsample of approximately 4.0 L was taken to determine moisture content for dry weight for each tree, where it was then dried in the lab.

Fine Fuels - The fine fuels component was considered to be all needles and associated twigs less than 6.4 mm in diameter. The fine fuels component was maintained in separate piles of lower, middle, and upper crown sections for each tree, since foliage moisture contents were likely to vary with crown height (Brown 1978). A random subsample approximating the size of approximately 4.0 L volume was taken from each crown section to determine moisture content. The fine fuels subsamples were then weighed to obtain wet weight.

The current year's growth (2004) was discarded, because many of the needles were not fully expanded, and samples were collected throughout the summer of 2004. The subsample was weighed again to determine the proportion of fine fuels that was current year's growth. This proportion was subtracted from the entire foliage component. After weighing, a random sample of 10 needle fascicles was taken from each fine fuels subsample, and the length and width of each fascicle was measured to determine leaf area. A tapered, bisected cylinder was used to determine surface area represented by each fascicle (Pearson et al. 1984 ; Madgwick 1964). After weighing while wet, this sample was dried and subsequently weighed so that surface area could be extrapolated to the entire tree's needle biomass. The dry weight proportion of total foliage biomass that was needles was determined from separating needles from twigs after the foliage subsamples were dried.

<u>Belowground Components</u>

For each tree, the entire coarse root system (>10mm diameter) was excavated with a backhoe or come-a-long. Prior to excavation, smaller roots ($\approx$ 10-20 cm) with potential to be damaged were removed by hand. After excavation, the root system was divided into four size classes: root crown (i.e. the massive structure directly beneath the tree bole), lateral roots >50mm in diameter, lateral roots 25-50mm in diameter, and lateral roots 10-25mm in diameter. Total weight of each root size class was weighed using a digital hanging scale. Subsamples were taken and weighed to determine moisture content for dry weight of each size class. Subsamples were dried and the dry: wet weight ratio was applied to its corresponding size class to determine total coarse root system dry weight.

Statistical Analyses

✦ Model Development

All allometric models will be developed with SPSS 13.0 (SPSS Inc. 2005). Models for each tree component will be developed for the three individual stands, for all sites combined, and pooled by density and age. The following criteria will be used to develop the best models for predicting biomass of lodgepole pine:

A.) The model must be biologically reasonable (Hilborn and Mangel 1997).

B.) The model must be of a form (linear or non-linear) that fits the data, although a model that does not produce a proper fit may achieve a higher R^2.

C. If two predictors are deemed to be relatively equal based on their biological plausibility, coefficient of determination (r^2/R^2), standard error / mean square error, and plot of the residuals, the most easily measured independent variable will be chosen.

Model Comparison

✦ Density and Age

To determine whether allometric models differ between stands of varying densities and ages, models pooled by density and age, will be compared using the extra sum of squares analysis for nested models (Bates and Watts 1988). In addition, equations for total aboveground biomass and coarse root biomass will be used to predict biomass in a different stand from where they were developed. For instance, pooled equations from the two young stands will used to predict above and belowground biomass in the older stand, to determine the degree of error produced from using an inappropriate model.

Geographic Location Comparisons

Models developed for mature lodgepole pine forests in this study will be compared to models developed by Pearson et al. (1984) in the Medicine Bow Mountains of southeastern Wyoming and by Comeau and Kimmins (1989) in British Columbia. Paired, two-tailed t-tests will be used to assess whether biomass estimates from this study differ statistically from biomass estimates produced from other models (Comeau and Kimmins 1989; Pearson et al. 1984; $\propto = 0.05$). In addition, we will compare actual biomass values from this study to values estimated from the application of our allometric models to determine whether our estimated biomass values are more similar to the actual values than estimated values calculated from the application of models developed by Pearson et al. (1984) and Comeau and Kimmins (1989). We anticipate completion of sample preparation and statistical analyses by spring, 2005.

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