

Description and Prediction of Individual Tree Biomass on Piñon (*Pinus edulis*) in Northern New Mexico

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Abstract—The purpose of this study was to gain reliable information on the distribution of aboveground biomass of an important component of the woodlands of north-central New Mexico, and to develop prediction equations that may be used to quickly compute biomass from relatively simple field measurements. Improved understanding of and ability to predict aboveground biomass distribution in open-grown piñon pine will provide a framework of information that will allow improved understanding of ecosystem processes.

Introduction

The piñon-juniper woodland forest type encompasses over 22.5 million hectares in the Western United States (Mitchell and Roberts 1999). In New Mexico, the piñon-juniper woodland type encompasses over five million hectares (Mitchell and Roberts 1999). The piñon component in this woodland type in New Mexico is predominately *Pinus edulis* Engelm. (Chojnacky 1994). Since the mid-1800s woody plant encroachment into former grasslands has increased in the southwestern United States (Van Auken 2000). Recent concerns of global warming, more specifically, the potential role of semi-arid woodlands in carbon sequestration, demands a more comprehensive understanding of aboveground biomass distribution in piñon within its natural range. Carbon fixed (sequestered) during the process of photosynthesis has the potential to undergo many fates within a plant. In woody plants, such as piñon, two of these fates are considered long-duration carbon pools—woody tissue and soil carbon pools. While these two fates are not entirely independent, a large portion of the carbon that ends up in the soil carbon pools is originally in the foliage.

Previously published work on the above ground biomass distribution of this species of piñon has primarily been focused on the merchantable (woody) components (Chojnacky 1985, 1988, 1994). However, others have examined both merchantable and non-merchantable aboveground components of the related species, singleleaf piñon (*P. monophylla* Torr. & Frem.) (Miller and others 1981).

The objectives of this study were two-fold; one was to describe the distribution of biomass allocation within individual, open-grown *P. edulis* trees. The second objective of this study was to develop a series of equations that predict component and total tree biomass of open-grown *P. edulis* trees, utilizing efficient field measurements.

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Materials and Methods

Trees used in this study were collected from a private ranch near the town of Guadalupe in Mora County, New Mexico (Lat. N 35.91358°; Lon. W 105.16884°). Trees were growing in a piñon–juniper woodland-grassland interface site. Principle tree species in this woodland type are piñon, oneseed juniper (*Juniperus monosperma* Engelm.), and Rocky Mountain juniper (*J. scopulorum* Sarg.). At lower elevations, the woodland is bordered by a blue grama (*Bouteloua gracilis*) dominated short grass prairie. At higher elevations the woodland is bordered by ponderosa pine (*Pinus ponderosa* Laws.) forest. The project site is situated at an elevation of 2100–2150 m on a sloping (30–40%), predominately southeast-facing slope. Soils found at the study site are classified as a Haplustolls-Rock outcrop complex (Sellnow 1985). The soils are derived from sandstone and shale, which produce a very stony, sandy loam across the site. Depth of soil within the site is variable, ranging from shallow to deep. Exposure of the underlying sandstone is evident throughout the area, and suggests high runoff and water caused erosion potentials.

The climate is semi-arid and annual precipitation is variable, averaging 446 mm annually (Western Regional Climate Center, Ocate, NM; <<http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nmocat>>). The majority of the precipitation occurs as rainfall in July and August. Mean annual snowfall is 940 mm occurring between October and May with the highest amounts in December and March. Mean annual temperature is 7.9 °C with mean January and July temperatures of –1.1 °C and 18.3 °C, respectively.

Eighteen open-grown piñon trees, age 14 to 33 years old, were selected for inclusion in this study. Open-grown was defined as no other tree canopy within two meters of the select tree. Other tree selection criteria included no observable physical damage, and free of insects and disease. Lastly, selected trees could not be forked within 30 cm of the ground line. Prior to harvesting, several tree attributes were measured for use in model development. These included: root collar diameter outside bark (0.1 cm); mean stem diameter outside bark at 30 cm above ground line (0.1 cm); mean stem diameter outside bark at 100 cm above ground line (0.1 cm); total crown height (0.1 m); height to first fork (if present) (cm); stem diameter outside bark 10 cm above and below base of fork (0.1 cm); crown width north-south axis (0.1 m); and, crown width east-west axis (0.1 m). Observed values are summarized in table 1.

Table 1—Median and range for attributes of 18 open-grown piñon used in this study. (n = 18 except for * where n = 13).

Attribute	Median	Range
Age (years)	18	14 – 33
Height (m)	1.56	0.4 – 3.8
Root Collar Diameter (mm)	65.85	18.9 – 174.6
Diameter @ 30 cm (mm)	43.35	6.0 – 139.8
Diameter @ 100 cm* (mm)	45.15	4.4 – 97.3
Crown Width (m)	1.25	0.3 – 3.5
Fresh Weight (kg)	5.94	0.2 – 118.3
Oven-dry Weight (kg)	3.36	0.1 – 75.6
Mean fresh = 20.24		
Mean dry = 12.36		

Harvesting was conducted from December 2000 through February 2001 while the trees were dormant. Tissues were separated into the following categories: foliage (needles); branches with diameters less than 0.50 cm; branches with diameters between 0.51 and 2.50 cm; branches with diameters between 2.51 and 5.00 cm; branches with diameters between 5.01 and 10.00 cm; and, branches with diameters greater than 10.01 cm.

Following separation, fresh and oven-dry weights were recorded for each tissue type. Oven-dry weights were obtained by placing tissues into large drying ovens at 120 °C for 24 to 72 hours until a constant weight was achieved. Drying time varied by tissue type.

Prediction Equation Construction

The relationship between field measurements and biomass data was nonlinear. Therefore, variables were transformed logarithmically (base e). The transformed variables were then evaluated through the use of forward, reverse, and stepwise regression techniques (PROC REG) (SAS Institute, 1999). The most important predictive variables were found to be total height, diameter at 30 cm, mean crown width, and their interactions. Stem diameter at 1 m was not considered, since more than 25% of the observations were less than 1 m in height.

Equations for each biomass fraction were evaluated for fit based on coefficient of determination (R^2), error mean square, and the C_p statistic (Mallows 1972). The precision of the developed equations is measured by percent bias, which is the deviation between observed and predicted observation expressed as a percentage (Faurot 1977). To evaluate the performance of the equations and compare predicted to actual values, predicted values were retransformed into arithmetic units. This process of retransformation may produce bias (Smith 1993), and several suggested correction factors were considered. However, similar to a study by Miller and others (1981), all suggested correction factors increased the bias in all predictions, and were dropped.

Results

The quantities of oven-dry biomass contained in various categories, from foliage to branches greater than 10 cm in diameter, provide a detailed description of structural biomass allocation in piñon trees (table 2). Across all trees sampled,

Table 2—Proportion of above ground biomass allocated to various tissue types and their corresponding moisture contents for eighteen open-grown piñon from northern New Mexico. SE = one standard error of the mean.

Biomass Fraction	Proportion of Total Tree Biomass		Moisture Content	
	(%)	SE	(%)	SE
Foliage	31.6	1.9	48.7	0.6
Branches				
< 0.5 cm	17.7	1.2	41.0	1.2
0.5 – 2.5 cm	31.1	0.9	43.0	0.9
2.5 – 5.0 cm	9.7	0.9	41.8	1.7
5.0 – 10.0 cm	12.4	1.6	38.3	2.4
> 10 cm	10.4	3.2	30.8	1.7
Dead	1.0	0.2	9.1	<0.1

foliage and branches between 0.5 and 2.5 cm in diameter make up the majority of above ground biomass on a dry weight basis constituting 32 percent and 31 percent of the above ground biomass, respectively (table 2). The smallest branch diameter class in this study, less than 0.5 cm, constitutes 18 percent of the above ground biomass, while the three largest branch sizes each constitute between 10 and 13 percent of the above ground biomass. Several of the smaller trees in the study did not contain any branch material greater than 10 cm in diameter, and this contributed to the larger standard error for this category of material (table 2). As trees became larger, the relative proportions of biomass allocated to the different categories became relatively stable (fig. 1). Two exceptions to this was the relationship between foliage biomass and branch biomass for branches between 0.5 and 2.5 cm. Only in the four largest trees did these support branches consistently comprise a larger proportion of aboveground biomass than did foliage. Other exceptions were to be expected, specifically that larger trees had a greater proportion of large branches as well as dead branches than did the smaller trees in the study (fig. 1).

Slightly less than half of the fresh weight of piñon foliage is water (table 2). The three smallest branch classes had similar moisture contents, ranging from 41 percent to 43 percent. As branch diameter increased, percent moisture content decreased to a low of 31 percent for branches greater than 10 cm in diameter (table 2). As expected, deadwood had the lowest moisture content, averaging nine percent moisture content.

All prediction equations included stem diameter at 30 cm and tree height as independent variables, and accounted for a substantial portion of the observed variability found within the data, evidenced by high R^2 values (table 3). All prediction equations developed, except for the prediction equation associated with foliage, also used mean crown width as an independent variable.

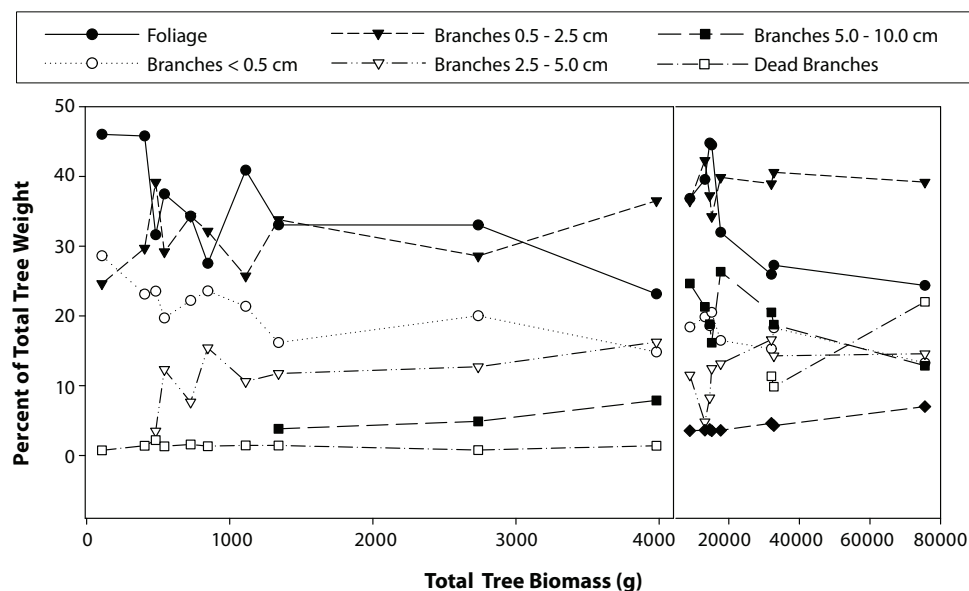


Figure 1—Allocation of above ground oven dry biomass into foliage and four living branch categories based on diameter and dead wood for eighteen open-grown piñon growing in northern New Mexico. (Note: vertical line between total tree biomass values of 4000 and 20000 reflects a gap in the data between the ten smallest and eight largest trees used in this study.)

Table 3—Prediction equations for estimating oven dry weight of the aboveground components of open grown piñon trees in north central New Mexico.

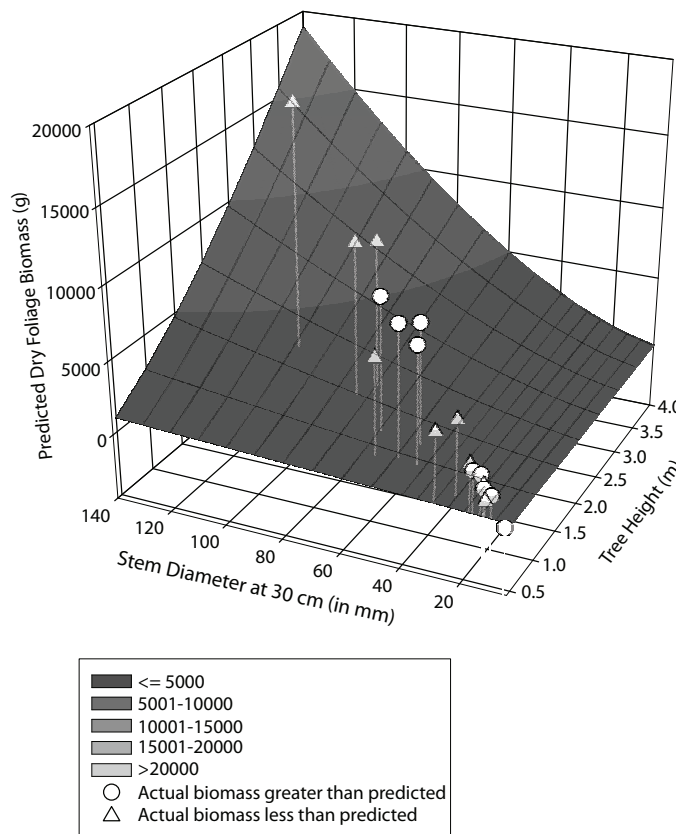
Biomass Fraction	Equation	Adj. R ²	Root MSE	Percent Bias
Total Biomass	$WT = 0.179 + 2.111 (D30) + 0.485 (HT * CW)$	0.984	0.240	0.334
Foliage	$WT = 2.070 + 1.179 (D30) + 0.285 (HT * D30)$	0.960	0.335	0.290
< 0.5 cm	$WT = 1.594 + 1.214 (D30) + 0.098 (D30 * HT) + 0.144 (D30 * CW)$	0.978	0.236	0.317
0.5 to 2.5 cm	$WT = -1.122 + 2.152 (D30) + 0.412 (HT * CW)$	0.985	0.232	0.373
2.5 to 5.0 cm	$WT = 3.136 + 8.863 (HT) + 0.431 (D30) - 4.140 (CW) - 1.717 (HT * D30) + 1.332 (D30 * CW)$	0.911	0.512	-0.050
> 5 cm	$WT = -10.642 + 4.290 (D30) + 0.026 (HT * D30) - 0.098 (D30 * CW)$	0.963	0.346	-0.235

WT = predicted component oven-dry weight (grams) in natural log scale, D30 = natural log of tree diameter at 30 cm on the bole, in mm, HT = natural log of tree height, in meters, and CW = natural log of mean crown width, in meters.

The Root Mean Square Error (MSE) associated with each equation is an indicator of the variability within each sample. The equation with the greatest amount of unexplained variability ($R^2 = 0.911$) is for branches 2.5 to 5.0 cm in diameter. This equation has the highest MSE, slightly greater than 0.5. The next highest MSE values were associated with equations predicting biomass found in the largest branches (> 5 cm diameter) and foliage, 0.346 and 0.335, respectively. The equations for the remaining two fractions and total tree biomass

had the lowest MSE values. Percent bias was less than 1% for all equations, with negative values showing a tendency to under predict biomass. Forking was introduced as a qualitative variable and was found to be insignificant in all fractions.

A graphic expression of prediction model accuracy involves plotting the response surface generated against the raw data. This method provides a mechanism to evaluate model applicability across the range of values used to develop the model. As an example, Figure 2 illustrates the response surface of foliage biomass. At low diameter values, increases in height result in only slight increases in predicted biomass, but at larger diameters, increasing height substantially increases predicted biomass.

**Figure 2**—Prediction equation response surface for dry foliage biomass and actual individual tree foliage biomass measures.

Discussion and Conclusions

Study-wide, foliage biomass represented the largest component of above ground biomass (32 percent); however, foliage amounts became proportionally less (46 percent to 22 percent) as trees became larger. This trend was also seen in a similar component analysis of singleleaf piñon (Miller and others 1981). A possible explanation for the foliage component in the present study accounting for a greater amount of the above ground biomass compared to other published reports, may be that only open grown trees were sampled. In the Miller and others (1981) study, no such constraint was required for tree selection. The open grown selection criteria resulted in the live crown of the sample trees being lower to the ground than would be found in trees growing in a denser stand. In denser stands, self-pruning and short needle retention duration occur. The estimate of the proportion of above ground biomass allocated to foliage in the current study is also considerably higher than that published for piñon growing in piñon-juniper stands (*P. edulis-Juniperus monosperma*; Grier and others 1992).

The smallest wood category partitioned in this study, branches with diameters less than 0.5 cm, constitute a small portion of the above ground biomass despite being the point of contact from which the foliage arises. Branches in the next larger size class (0.5 to 2.5 cm diameter) provide the support and arrangement for the photosynthetic tissue. Despite using different branch diameter categories, the proportion of biomass in the two smallest branch classifications (< 2.5 cm) presented in the current study are slightly higher (48 percent versus 32 percent) than previously published values for singleleaf piñon (Miller and others 1981 [smallest two tree categories only]). Again, the sampling criteria of open grown trees, as well as the higher proportion of smaller trees in the current study may be contributing to the higher proportion of biomass allocated to tissues associated with supporting foliage.

Management Implications

Improved understanding of the above ground biomass distribution in open-grown piñon, such as that generated in this report, will provide necessary information that will allow a better understanding of ecosystem function in semi-arid woodlands. The information generated in this study in addition to information on other above and below ground biomass pools should lead to both an improved understanding of energy and carbon flows in these ecosystems.

Estimations of volume and biomass in piñon have historically been difficult. Chojnacky's (1985) equations for estimating volume in singleleaf piñon (*P. monophylla* Torr. & Frem.) in the central Rocky Mountain States contained error rates well above 25 percent for specific size classes found in certain regions. It is the great physical variability exhibited by this species throughout the Western United States, which results in the dilemma of whether to create wide-ranging equations with unsatisfactory error rates, or localized equations of greater accuracy that may prove even less accurate when applied to other areas.

In 1994, Chojnacky published total volume equations for piñon in New Mexico. Compared to his 1985 study, the New Mexico equations exhibited good fit, with high R^2 values slightly greater than 0.9. However, it was reported that the New Mexico equations predicted substantially greater volume than those developed for Colorado and Arizona.

In this study, percent bias in all equations was less than 1 percent. The smallest bias was found within the two largest biomass fractions (2.5 to 5.0 cm and > 5.0 cm). There was less variability for observations within these fractions, as

only the largest trees within the sample contained biomass of these diameters. Similar equation development by Miller and others (1981) yielded bias estimates ranging from 1 to 5.3 percent. The trees within that study were singleleaf piñon growing in Utah, with a larger range of heights compared to the current study (from a mean of 2.0 m in the smallest diameter class, to over 9.0 meters tall in the largest class).

Overall, the prediction equations perform well and describe a large proportion of the variability within the data. These equations are reliable predictors of biomass for piñon trees within this and similar regions. It should be noted that the equations should only be utilized on piñon within the same size range as the study, mainly trees approximately 4 m in height. Trees larger than 4 m will likely have their biomass overestimated by the equations, as the response surface shows a rapid increase.

Acknowledgments

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