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Short Communication

Biomass and carbon data from blue oaks in a California oak savanna

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ABSTRACT

Stem circumference at breast height (1.4 m above ground), tree height, distance from the ground to the base of the crown, and crown radii from the stem to the average drip line were measured for fourteen blue oak (*Quercus douglasii*) trees from a California site. The trees were felled, and we determined mass of stems, branches, twigs, and foliage; and analyzed carbon and nitrogen in branch and stem (0.44% N, 45.85% C) and leaf (2.13% N, 45.11% C) samples. Equations estimating biomass from diameter at breast height (dbh) or diameter at root collar (drc) were developed through regression. We applied our equations to blue oak data from the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis Program (FIA) database. Our biomass and carbon estimates were generally comparable to but exceeded FIA's predictions by about 15% and 7%, respectively.

1. Introduction

Accurate tree biomass and carbon estimation is important for understanding ecosystem processes, for calculating carbon sequestration values, and for management of both bioenergy and traditional timber product harvests. Because of variations in growth forms, biomass estimation has historically utilized equations that are site- and species-specific. Estimates of biomass for blue oaks (*Quercus douglasii*) are few, and root biomass has been emphasized due to the interest in interactions between these trees and annuals in California grasslands and woodlands [1,2].

However, blue oaks are a key component of California ecosystems and estimates of their above ground biomass can fill an important data gap. According to the U.S. Forest Service's Forest Inventory and Analysis (FIA) Program database [3], California oak species are the most common species group in the state, accounting for about one-fourth of all trees larger than 2.54 cm (1 inch) diameter at breast height (dbh; 1.4 m above the ground). Oak ranks fourth behind pines (*Pinus* spp.), true firs (*Abies* spp.), and Douglas-fir (*Pseudotsuga menziesii*) in basal area, accounting for 15% of California's forest basal area. Blue oak is the fourth most common oak species in terms of total trees, following canyon live oak (*Quercus chrysolepis*), interior live oak (*Quercus wislizeni*), and California black oak (*Quercus kelloggii*); but in terms of basal area, blue oak is third, behind live and black oaks.

The work presented here utilized previously unpublished total biomass data collected during a larger study by Karlik and

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McKay [4] whose objective was quantification of leaf mass and evaluation of leaf mass estimation methods for a stand of native blue oaks. We used available data from harvested trees to develop biomass estimation and carbon conversion equations. Although our sampled population was small and data primarily limited to those collected for another objective, we know of no other estimates of blue oak above ground biomass in California.

2. Materials and methods

2.1. *Field and laboratory methods*

In July 2000, a grove containing 14 blue oak trees was selected on a site on private land in the Sierra Nevada foothills near California Hot Springs, approximately 80 km northeast of Bakersfield (Fig. 1). The site was a 15° (27%) inclined northeast-facing slope at 975 m elevation, with a 1 m deep granitic sandy loam soil over rock [5]; and received 40–50 cm of annual precipitation, primarily in winter. The stand of trees, established from natural acorn dispersion, appeared not atypical of blue oaks found in the oak savannas of the foothill areas of the southeastern San Joaquin Valley. The trees had received no cultural attention, such as pruning, irrigation, or fertilizer.

The single 50 m^2 site was established so as to encompass the crown projections of the 14 trees. Latitude–longitude coordinates of 35°51′53″N (35.86472) and 118°42′33″W (−118.70917) were determined with a Global Positioning System. The trees were numbered, and the position of each tree was noted.

Standing trees' stem circumferences at breast height (1.4 m) were measured with a steel tape to 1 cm precision. Tree height (measured with a telescoping pole), distance from the ground to the base of the crown, and crown radii in the four cardinal directions from the stem to the average drip line were measured to 10 cm precision.

Following measurement of the 14 standing trees, each tree was felled with a chain saw approximately 5 cm above the soil surface. Stump diameter was measured in two perpendicular directions and the number of sapwood rings was counted. Each felled tree was separated in the field into sections defined by diameter size as twigs (<2 cm in diameter) with leaves, branches (2–10 cm), and stems (>10 cm); all sections included bark. Mass of branches and stems was determined immediately in the field after harvest. The twigs with leaves were transported to the laboratory, all leaves were removed for drying, and twig mass was measured. As the focus of the primary study [4] was foliage and not green wood biomass, and as twigs did not constitute a major part of the trees' biomass, green twig mass was not measured immediately after harvest; consequently there was some unquantified moisture loss in twig material. Leaves were placed in paper bags and dried for two weeks in a vacant greenhouse with daily maximum temperatures of about 65 °C and relative humidity less than 20%. Mass values for bags of leaves were determined and masses summed for each tree. Mass from all material from the trees was measured—there was no subsampling in this part of the study.

To obtain a green-to-dry mass conversion factor for wood, an additional tree from the same site was harvested in July 2003. (Moisture content was not needed for the Karlik and McKay [4] study.) Mass for 4 samples of stems, branches, and twigs was measured in the field immediately after harvest, and then the samples were placed in a laboratory oven at 50 °C. Wood was checked at biweekly intervals, and when less than 1% change occurred in mass between measurements, the wood was considered to be dry. Wood was checked after additional drying time to verify that mass had stabilized.

Six dry samples from the 2003 harvest, two each from stem segments, branch segments, and leaves; were analyzed for carbon and nitrogen content by the University of California

Fig. 1 – Overview of blue oak study site, looking east toward the Sierra Nevada Mountains. Inset: Tree number one, showing irregular stem shape. This tree had a hollow center and had lost about 80% of its biomass.

DANR laboratory. Although bark was not sampled separately, no attempt was made to remove bark from the samples. Total carbon and nitrogen content of the samples was obtained using the Carlo Erba flash combustion method, Method 972.43, of the Official Methods of Analysis of AOAC International.

2.2. *Modeling analysis*

Diameter measurements were used to predict biomass. Although California oak diameter measurements are generally dbh, similar oak species in Arizona and New Mexico are measured using diameter at root collar (drc); hence, two models were developed from dbh and drc measurements. FIA defines drc as diameter measured near groundline but above any root collar swell [3]. Diameters measured at 5 cm above groundline were considered to approximate this definition except for trees 3 and 10, which had excessive butt swell (note dbh-to-drc ratio <0.5 in Table 1). Hence, a regression model was developed (Table 2) from the other 12 trees to estimate a more appropriate drc for trees 3 and 10.

3. Results and discussion

The moisture content (MC = [green mass·dry mass^{-1}] − 1) results obtained from the single tree sampled for that purpose were 0.305 (SE 7.3% of MC), 0.510 (SE 3.0% of MC), and 0.521 (SE 1.9% of MC) for twig, branch, and stem samples, respectively. Those MC results were then applied to calculate mass ratios for data from other trees. Both stem and branch samples were found to have a dry mass of 0.66 of the green mass, while dry twig samples had a mass of 0.76 of the green mass (SE 3.3%, 2.4%, and 19.7% of ratio for respective stem, branch, and twig; PROC SURVEYMEANS using Taylor series variance calculation, ©SAS Institute Inc. [6]). The carbon content of branch and stem material combined ranged from 45.06% to 46.70%, with a mean of 45.85% (SE 0.276%); nitrogen content ranged from 0.38% to 0.54%, with a mean of 0.44% (SE 0.028%). Carbon and nitrogen content of the two dry leaf samples was 45.11% (SE 0.095%) and 2.13% (SE 0.095%). These means can be used to convert biomass to carbon or nitrogen content for respective wood-bark or foliage material.

Dimension and biomass measurements are summarized in Table 1. Regression was used to estimate dry mass from diameter for 13 of the trees. Tree number one was excluded because of its irregular stem shape, and because extensive dieback and decay had resulted in a hollow center and loss of approximately 80% of its biomass. Biomass modeling used simple linear regression and natural log transformation of biomass and diameter data. This model form is widely used for biomass estimation and extrapolated reasonably well to small trees (important because no trees with diameters of 1–10 cm were included in this study). Model parameters were estimated for foliage, total wood and bark (stem, branches, twigs, and bark), and total above ground dry mass, with separate models for dbh and drc predictor variables (Table 2). Because data were log-transformed, a slight theoretical bias results when transforming the results of the equation back to the original units [7]. We report two correction factors [8,9] for interested readers but they are less than 1 or 2 percent, which has little effect on results.

Because equations were based on trees sampled from only one site, it is understandable to question their applicability. Because we know of no other blue oak or California oak biomass studies, we compared values calculated from application of our model to blue oak measurements in the FIA database with FIA's own estimates.

FIA calculates biomass and carbon from volume equations (for oak, [10]), wood density factors [11], and national-scale biomass equations for hardwoods to fill in gaps for

Table 1 – Blue oak dimensions and biomass of trees harvested near California Hot Springs, California.

Tree no.	Height (m)	Height to crown (m)	Crown radius (m)	Sapwood rings (no.)	dbh[a] (cm)	drc[b] (cm)	dbh to drc ratio	Dry leaf mass (kg)	Green weight in kg of wood and bark biomass		
									<2 cm (twigs)	2–10 cm (branches)	>10 cm (stems)
1[c]	7.4	3.0	1.1		64	85	0.75	3.75	27.5	43.6	617.0
2	6.7	2.6	2.0	112	25	30	0.83	9.75	104.0	84.4	215.0
3[d]	4.7	1.5	1.1	89	14	29	0.48	2.21	15.5	14.3	43.2
4	7.8	1.5	1.4	97	18	22	0.82	5.23	36.4	26.0	108.0
5	7.5	3.0	1.8	130	24	30	0.80	6.79	42.0	58.6	190.0
6	5.9	1.4	1.2	70	12	14	0.86	1.95	11.3	18.3	30.6
7	7.2	1.6	1.1	113	18	22	0.82	4.42	22.5	41.8	101.0
8	6.7	1.7	1.5	103	19	23	0.83	5.38	41.3	24.0	118.0
9	9.9	2.4	3.6	172	42	49	0.86	29.30	306.0	265.0	883.0
10[d]	4.2	1.4	1.1	86	12	25	0.48	1.83	21.3	5.7	26.1
11	6.8	2.3	1.5	76	19	22	0.86	5.23	29.7	31.7	90.8
12	6.3	1.7	1.2	72	13	17	0.76	2.20	14.1	11.2	46.0
13	7.5	2.0	1.8	95	22	29	0.76	9.04	47.6	73.6	183.0
14	4.4	2.4	2.1	86	17	21	0.81	5.93	55.8	29.6	87.0

[a] Diameter at breast height measured 1.4 m above groundline.
[b] Diameter at root collar uniformly measured 5 cm above groundline.
[c] Hollow stem, about 80% biomass missing.
[d] Trees with excessive butt swell; drc not used in analysis, instead drc modeled from equation 1.

Table 2 – Blue oak equations for estimating dry biomass and other dimensions from either diameter at breast height (dbh; diameter 1.4 m above groundline) or diameter at root collar (drc; diameter 5 cm above groundline).

Model prediction (Y)		Model parameters					Log correction factors[a]	
Eq. no.	Equation form[b]	β_1	β_2	n	SSE[c]	[d]R^2	Duan [9]	Baskerville [8]
Drc (cm)								
1	$Y = \beta_1\ dbh^{\beta 2}$	1.142 3	1.024 3	12	37.721	0.991	1.001	1.001
Dbh (cm)								
2	$Y = \beta_1\ drc^{\beta 2}$	0.904 5	0.967 3	12	20.197	0.991	1.001	1.001
Foliage biomass (kg)								
3	$Y = \beta_1\ dbh^{\beta 2}$	0.008 2	2.199 3	13	12.269	0.980	1.012	1.014
4	$Y = \beta_1\ drc^{\beta 2}$	0.004 6	2.239 7	13	12.235	0.980	1.013	1.016
Wood and bark biomass of all stems, branches, and twigs (kg)								
5	$Y = \beta_1\ dbh^{\beta 2}$	0.062 8	2.584	13	3385.719	0.996	1.006	1.008
6	$Y = \beta_1\ drc^{\beta 2}$	0.032 1	2.631 6	13	12,705.503	0.983	1.008	1.010
Total above ground biomass (kg) (stem, branches, twigs, bark, and foliage)								
7	$Y = \beta_1\ dbh^{\beta 2}$	0.068 3	2.569 7	13	3709.821	0.995	1.007	1.008
8	$Y = \beta_1\ drc^{\beta 2}$	0.035 1	2.616 9	13	13,325.525	0.983	1.008	1.010

[a] Although logarithmically transformed regression results are often corrected for bias, we did not "correct" β_1. Instead we give two possible corrections for interested readers that can be multiplied times β_1.
[b] Parameters for equations 1–8 were estimated by using log-transformed linear regression.
[c] Sum of squares error from regression was recalculated in terms of prediction units (Y): $SSE = \sum_{i=1}^{n} (Y_i - \hat{Y})^2$
[d] R^2 statistic recalculated in terms of prediction units (Y): $R^2 = 1 - (SSE/CSST)$, where $CSST = \sum_{i=1}^{n} (Y_i - \overline{Y})^2$

nonmerchantable material [12,13]. We applied our equation 5 (Table 2) to 2742 blue oak trees sampled by FIA throughout California [3] for comparison to FIA estimates (which exclude foliage biomass). Diameter at breast height ranged between 2.5 and 101 cm, and only noncull trees showing no evidence of rotten or missing cull volume were selected. Our equation produced results corresponding most closely to FIA's higher predictions: on average, our biomass equation results exceeded FIA data estimates by about 15% (Fig. 2), and our carbon estimates by an average of 7%.

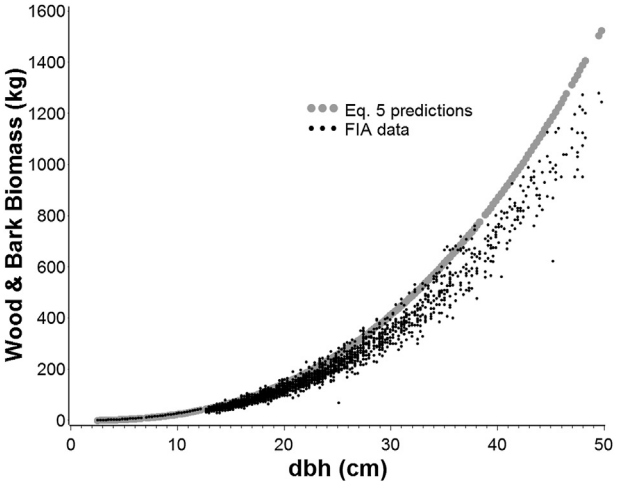

Fig. 2 – Comparison of our biomass model (eq. 5) to FIA biomass calculations using data for blue oak in California. FIA estimates biomass of saplings (dbh < 12.7 cm) from Jenkins et al. [12] equations which do not include height; therefore no variation (in black dots) is shown for < 12.7 cm dbh.

4. Conclusions

Ours is California's first study of blue oak biomass from felled-tree sampling. Utilization of trees already destructively sampled for another study was an efficient use of resources, but it resulted in a small sample size. Nevertheless, these initial data are now available for addition to any future blue oak datasets and can play a part in achieving a fuller understanding and better estimation of growth in this species. Our work should be duplicated in a few more sites throughout California's oak range to verify results, and both smaller and larger trees should be sampled to avoid model extrapolation. Also, moisture content and carbon sampling should be done on the same trees for which green mass is measured.

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