# Woody Root Biomass of 40- to 90-Year-Old Blue Oaks (*Quercus douglasii*) in Western Sierra Nevada Foothills[1]

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***Abstract**: This research examined biomass of blue oak (*Quercus douglasii *Hook. and Arn.) roots at the University of California Sierra Foothill Field and Range Research and Extension Center. Six blue oak root systems were excavated by trenching around the tree and removing the "root ball" with a backhoe. Before tree removal, soil from two 1-m*$^3$ *trenches was sieved and roots were collected to estimate root biomass outside the root ball. Root ball mass ranged from 7 to 184 kg, and estimated total root biomass ranged from 12 to 193 kg. Root ball mass correlated with age, diameter at breast height, and bole mass. However, because of the small sample size, these relationships cannot yet be used for predicting belowground biomass.*

Although little information regarding coarse root biomass of tree species exists, these large structural roots have great value and importance for ecosystem processes. Coarse roots (generally, all roots >2 mm) not only offer physical support for the tree, but also influence the distribution of fine (<2 mm) roots, the roots responsible for water and nutrient uptake. Coarse roots also serve as a carbon and nutrient sink, and as such they represent an important component of biogeochemical studies of forest and woodland ecosystems (Nadelhoffer and Raich 1992, Vogt and others 1986).

Historically, most coarse root studies focused on morphology (Henderson and others 1983, Lyford 1980, Stout 1956) or biomass, in relation to stand productivity (Baskerville 1965, Santantonio and others 1977, Westman and Rogers 1977). Morphological studies require careful dissection to expose root systems and often include detailed mapping procedures. Biomass studies, on the other hand, have generally been less precise, and methods included hydraulic excavation (White and others 1971), excavation with large machinery (Honer 1971, Johnstone 1971, Westman and Rogers 1977), and measurement of naturally uprooted trees (Santantonio and others 1977). In some instances, annual coarse root production has been measured as well as total biomass (Deans 1981, Kira and Ogawa 1968). A typical goal of biomass studies has been to obtain allometric relationships between root mass and more easily measured parameters, such as diameter at breast height (DBH) and tree height. With these relationships, the amount of biomass allocated belowground can be determined for an entire stand.

For this study, six blue oak (*Quercus douglasii* H. and A.) trees were excavated in the Sierra Nevada foothills, northeast of Sacramento. Goals of the study included determining biomass distribution radially and with depth, as well as determining allometric relationships that would facilitate whole-stand belowground biomass estimation. This paper reports on allometric relationships between root mass and aboveground parameters (diameter, height, bole mass); biomass distribution data will be reported elsewhere.

## Methods

In spring 1995, six blue oaks were sampled from three different areas of the University of California Sierra Foothill Field and Range Research and Extension

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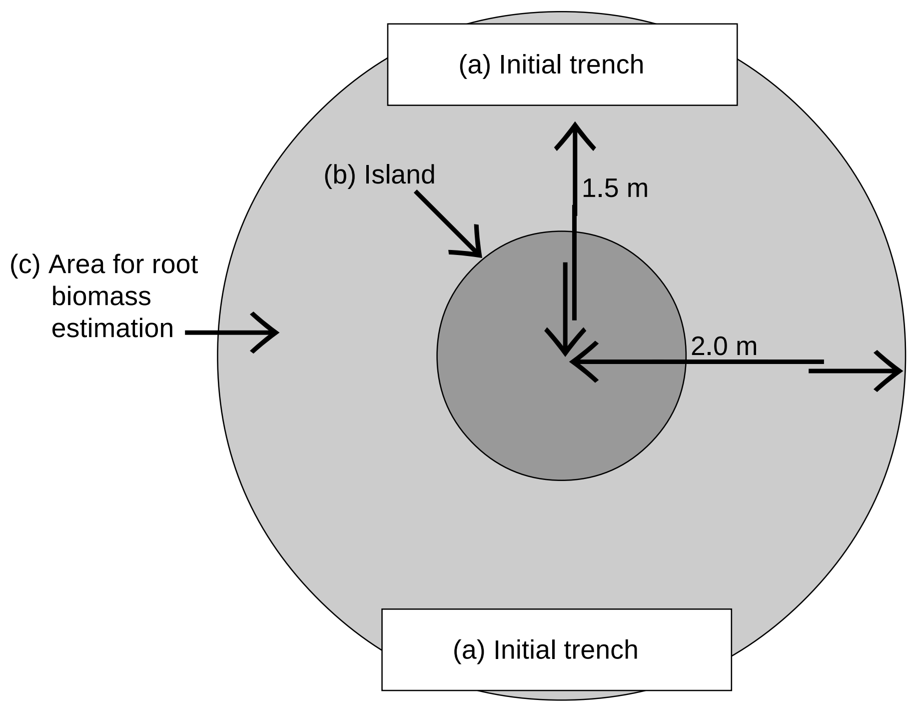
Center (northeast of Sacramento and near Browns Valley, California). This station has a mean annual precipitation of 73 cm and mean annual temperature of 15 °C. Soils are classified as fine, mixed, thermic Typic Haploxeralfs and are derived from basic metavolcanic rock (Dahlgren and Singer 1991). Vegetation is oak woodland with annual grasses. Dominant trees include blue oak and foothill pine (*Pinus sabiniana*). Shrub species include poison oak (*Toxicodendron diversiloba*) and manzanita (*Arctostaphylos manzanita*). *Bromus* spp., *Avena fatua*, *Elymus glaucus*, and *Hordeum* spp. are common grasses at the site.

Trees were selected on the basis of backhoe accessibility and absence of neighboring trees within 5 m. In addition, trees of various sizes were selected in order to obtain regression equations relating tree size (diameter, height, bole mass) to root mass. Aboveground measurements included DBH, basal diameter (at ground level), height, and bole (aboveground portion of tree) mass. Ages were determined using cross sections from the base of the bole.

Two 1-$m^3$ trenches were excavated for each tree to estimate the biomass of roots not recovered during the root ball excavation. Trenches were located 1.5 m from the tree and were approximately 2 m long, 0.5 m wide, and 1 m deep (*fig. 1*).

**Figure 1**—Schematic diagram of (a) trenches used for total root biomass estimation, (b) "island" of soil and roots remaining after connecting and widening trenches, and (c) 2-m-radius circle within which root biomass was estimated.




Soil from these trenches was sieved through a 5-cm (2-inch) mesh, and roots were collected. Roots were hand washed and weighed. Subsamples were oven dried at 60 °C for 5 days, and dry weight was determined. Root biomass per unit volume in trenches was used to estimate root biomass contained in the area between the root ball and a circle with 2-m radius (*fig. 1*).

After the trench excavations, "root balls" (root crowns and the lateral roots attached to them) were removed with a backhoe. The two trenches described above were connected to create a trench encircling the tree. This 1-m-deep trench was then widened inward (i.e., toward the tree), leaving an "island" of soil approximately 1.5 m in diameter. Soil around the root ball was loosened by inserting the backhoe at the base of the "island" and lifting up on it. The root ball was then removed by attaching a chain to the stump and pulling the stump and root ball out of the soil with the backhoe. These roots were washed with a fire hose, and oven dry weight was determined on subsamples.

# Results

Aboveground parameters, root ball mass, and total root biomass estimates are shown in *table 1*. Tree age ranged from 40 to 90 years. Basal diameter ranged from about 12 cm for the youngest tree to almost 40 cm for the oldest trees. Tree height and bole mass generally increased with increasing basal diameter. However, the relationship between age and basal diameter was less strong.

***Table 1—Size, age, and biomass data for six excavated blue oak (*****Q. douglasii*****) trees***

| Tree no. | Diameter at breast height | Basal diameter | Height | Age | Bole mass | Root ball mass[1] | Total root biomass[2] |
|---|---|---|---|---|---|---|---|
| | *cm* | *cm* | *m* | *yr* | *kg* | *kg* | *kg* |
| 1 | 7.6 | 11.9 | 4.0 | 42 | 30.6 | 11.5 | 16 |
| 2 | 8.1 | 13.0 | 4.0 | 48 | 28.5 | 7.5 | 12 |
| 3 | 10.7 | — | 17.2 | 40 | 49.8 | 17.2 | 23 |
| 4 | 13.7 | 19.1 | 5.0 | 42 | 95.3 | 10.3 | 15 |
| 5 | 29.0 | 39.6 | — | 72 | 651.9 | 125.2 | 131 |
| 6 | 33.3 | 39.1 | 9.8 | 90 | 709.4 | 184.4 | 193 |

[1]Root ball mass refers to dry mass of crown and lateral roots removed by the backhoe.

[2]Total root mass includes root ball dry mass and an estimate of remaining roots, determined from 1-$m^3$ trenches.

To determine allometric relations, the logarithm of total root mass was regressed against the logarithms of the following aboveground parameters: DBH, basal diameter, bole mass, and height (*table 2*). Logarithmic transformations were used because variance in root biomass tends to increase as independent variables increase (Santantonio and others 1977). Multiple regression with DBH and height as independent variables yielded the following equation:

$$\log y = -0.810 - 1.26 \log x_1 + 5.00 \log x_2 \qquad (R^2 = 0.96)$$

where y is root mass, $x_1$ is DBH, and $x_2$ is height.

***Table 2—Allometric equations derived from six excavated blue oak (*****Q. douglasii*****) trees***[1, 2]

| Equation no. | x | b (y intercept) | m (slope) | $R^2$ |
|---|---|---|---|---|
| 1 | DBH | –0.559 | 1.81 | 89.4 |
| 2 | BD | –1.34 | 2.19 | 90.0 |
| 3 | Stem | –0.079 | 0.79 | 90.8 |
| 4 | Height | –0.749 | 3.01 | 93.9 |
| 5 | $(DBH)^2$*Height | –0.584 | 0.689 | 87.3 |

[1]Equations 1–5 follow the model y = mx + b, where y is the logarithm of root biomass (kg) and x is the logarithm of the tree parameter listed.

[2]Abbreviations are as follows: DBH, diameter at breast height (cm); BD, basal diameter (cm); Bole, aboveground mass (kg); Height, tree height (m).

As *figure 2* indicates, the relationship between aboveground parameters and root mass may not be as strong as $R^2$ values suggest. When the two largest trees are not included in regressions of root mass against DBH, height, and stem mass, $R^2$ values are less than 0.01. For the smaller trees, stem mass correlated less to root mass than did DBH or height.

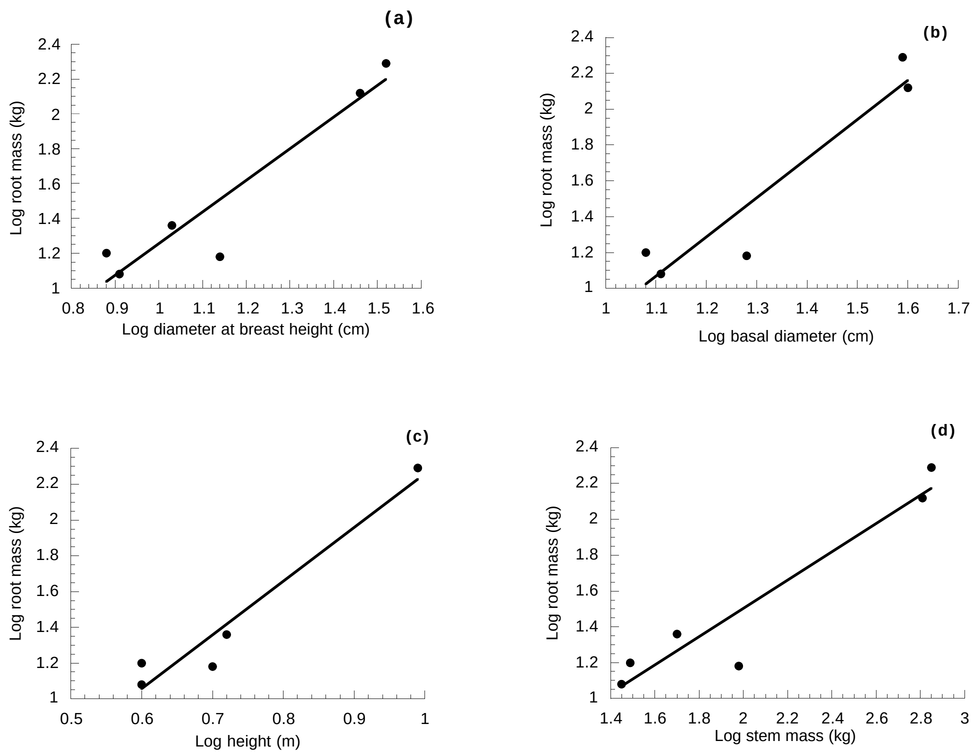



**Figure 2**—Relationship between the logarithm of root biomass (kg per tree) and the logarithm of the following aboveground dimensions: (a) diameter at breast height in cm, (b) basal diameter in cm, (c) tree height in cm, and (d) aboveground (stem) biomass, in kg per tree.

# Discussion

Santantonio and others (1977) extensively reviewed information available on total root biomass and demonstrated a linear relationship between log DBH and log root biomass using 19 different tree species (both hardwood and softwood). Despite the small sample sizes often involved in root system studies, the allometric relationships between aboveground parameters, such as DBH, height, or bole mass, and root biomass seem fairly consistent. However, allometric relationships for individual stands must be determined to estimate carbon or nutrient flow for those stands or watersheds.

Allometric equations from this study and studies of other species are compared in *table 3*. Because excavation methods differ and some sample sizes are small, valid statistical comparisons between these regression equations cannot be made. However, some general observations can be made. The regression equations for *Q. ilex*, an oak species found in montane forests of Spain, are similar to those for *Q. douglasii*. Both species grow in a Mediterranean climate, where summer drought would make extensive root systems advantageous. *Eucalyptus signata* also grows in a seasonally dry climate, and its regression of root mass against DBH is very similar to that of *Q. douglasii*. The regression equation for *Q. robur,* excavated from a Swedish woodland, differs slightly from that of *Q. douglasii*. However, the equation for *Q. robur* is more similar to that of *Q. douglasii* than that of *Pinus contorta*.

*Table 3—Allometric equations for blue oak (***Q. douglasii***) and 5 other tree species reported in the literature*[1]

| Species | b (y intercept) | m (slope) | $R^2$ | *n* (no. of samples) | Reference |
|---|---|---|---|---|---|
| | (a) Regressed against log DBH (cm) | | | | |
| *Quercus douglasii* (California) | -0.559 | 1.81 | 89.4 | 6 | this study |
| *Quercus ilex* (Spain) | -1.047 | 2.191 | 73 | 32 | Canadell & Roda (1991) |
| *Eucalyptus signata* (Australia) | -0.599 [2] | 1.903 | 71.5 | 11 | Westman & Rogers (1977) |
| *Fagus grandifolia* (NewHampshire) | -1.400 | 2.316 | 0.98 | 14 | Westman and others (1974) |
| Mixed conifer (Oregon) | -2.407 [1] | 2.461 | 89.8 | 40 | Honer (1971) |
| | (b) Regressed against log Stem Mass (kg) | | | | |
| *Quercus douglasii* (California) | -0.079 | 0.790 | 90.8 | 6 | this study |
| *Quercus ilex* (Spain) | -0.212 | 0.894 | 83 | 11 | Canadell & Roda (1991) |
| | (c) Regressed against log DBH$^2$*H (cm$^2$m) | | | | |
| *Quercus douglasii* (California) | -0.584 | 0.689 | 87.3 | 6 | this study |
| *Quercus robur* (Sweden) | 0.1145 | 0.4619 | — | 3 | Andersson (1970) |
| *Pinus contorta* (Canada) | -1.702 [1] | 0.806 | 90.0 | 221 | Johnstone (1971) |

[1]The model is log y = b + m log x , where y is total root biomass and x is (a) diameter at breast height (DBH), (b) aboveground biomass (bole mass), and (c) (DBH)$^2$ times height (H).

[2]Original value was obtained using different units. The value shown is the intercept obtained when DBH is in cm, mass is in kg, and height is in m.

The method used to determine total root biomass in this study probably underestimated root biomass. Trenches for estimating root biomass not included in the root ball were located 1.5 to 2.0 m from the tree (*fig. 1*). These trenches were used to estimate biomass between the root ball and a circle 2.0 m in diameter. This method could underestimate biomass in two ways. First, root biomass may be greater at 1 m from the bole, for example, than at 1.5 m from the bole. Second, roots appeared to extend farther than 2 m from the bole. Estimated amounts of root biomass outside the root ball were small compared to root ball mass. Thus, for purposes of stand-level estimation of belowground biomass, these estimations are probably adequate.

Allometric equations like those presented here can be used for estimating belowground biomass at a stand level. Root biomass can be determined from height and diameter, which can be measured nondestructively on a large number of trees. Stem mass regressions are generally less practical. However, if biomass of trees were determined following a harvest, the stem mass regressions could be used for determining belowground biomass. Although our equations had high $r^2$ values and were similar to others reported in literature, more trees should be excavated before applying the equations. Trees with DBH between 14 and 29 cm and greater than 34 cm should be included to make the regression more accurate and useful for large-scale estimations.

The nature of blue oak development and reproduction must also be considered before applying these allometric equations. Blue oaks can resprout if the aboveground portion is damaged (by fire, for example). Resprouted trees may have a large root system despite their small size. The trees used in this study did not appear to have developed from sprouts. Consequently, the equations reported may not be useful for a stand where many trees have resprouted. Also, these trees were single-stemmed and open-grown. Following disturbance or when grown at higher densities, blue oak root systems may develop differently from those that we measured.

## Summary

This study provides valuable data on coarse woody root biomass. Numerous regression equations were tested for their ability to predict coarse root biomass from aboveground tree measurements. Multiple regression with height and DBH as independent variables resulted in the highest correlation coefficients. These two variables can be measured relatively easily, so the regression equation could be very useful for predicting coarse root biomass on a larger scale. However, before the equations reported here can be used with confidence, more trees (especially with DBH between 14 and 29 cm) should be analyzed.

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