Accounting for Variation in Root Wood Density and Percent Carbon in Belowground Carbon Estimates

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Abstract

Little is known about belowground biomass and carbon in tanoak. Although tanoaks rarely provide merchantable wood, an assessment of belowground carbon loss due to tanoak removal and Sudden Oak Death will inform conservation and management decisions in redwood-tanoak ecosystems.

The carbon content of woody biomass is a function of density and the proportion of carbon in dry biomass. Whole-tree basic wood density or specific gravity estimates are often available to facilitate calculation of forest biomass, and contemporary carbon analyses generally assume that carbon comprises 50 percent of the dry biomass for the whole tree. Less is known about root wood density and carbon, or variations within root systems. Quantifying root wood density and carbon content changes along the length of a root will enable more accurate estimation of belowground carbon, and support development of equations predicting carbon from easily measurable aboveground variables, such as dbh.

To analyze root density and carbon content at different locations within root systems, tanoak trees were first removed using an excavator. Root wood samples were taken from four locations within the root system: within the stump (aboveground), within the lignotuber, at the start of the root (adjacent to the lignotuber) and at the end of the root (near tip).

We did not detect significant differences in root wood density between samples collected at different distances from the stem or between different sizes of roots. Percent carbon was highest at the sample farthest from the lignotuber, while samples from the other locations were not statistically different. Root carbon also varied among root systems sampled.

Key words: belowground, biomass, carbon, lignotuber, *Notholithocarpus densiflorus*, roots, tanoak, wood density

Introduction

Due to challenges in sampling and measurement of tree roots, little is known about root system biomass and carbon (C) content (Böhm 1979). The C content of roots is a function of root biomass and the proportion of carbon in dry root biomass. Accurate estimates of root biomass are difficult to obtain. Any variability in root wood density and C content within and between root systems will introduce uncertainty into estimates of belowground C. An understanding of patterns of belowground density and C within root systems is needed to guide belowground sampling methods and support calculations or predictions of belowground C.

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One method of sampling roots (Achat et al. 2008) involves digging a trench next to the root system of interest and mounting a grid frame on the trench wall to count or map roots. This method reveals gradients in root distribution with depth, but ignores root length. Extracting entire roots gives root volume and biomass, but requires care further from the stem where roots narrow, weaken, and become intertwined with roots from neighboring trees. Root volume equations can be fitted to diameter and length data. Volume estimates can be converted to biomass and carbon estimates once patterns of root density and carbon content have been described.

Aboveground biomass and C allocation patterns have been described for many species. Variations in light interception as well as interspecific differences in wood density are major factors determining variations in growth among trees (King et al. 2005). Wood density is positively correlated with crown area and depth and can be a reasonable predictor of light demand of some species (Aiba and Nakashizuka 2009, Nock et al. 2009). Wood density also generally decreases along the length of the stem (Correia et al. 2010, Espinoza et al. 2004, Park et al. 2009, Paul et al. 2008).

Radial patterns of growth (growth from pith to bark) are different in stems branches and roots, supporting the hypothesis that wood in different positions in a tree has different physiological or mechanical roles (Peterson et al. 2007). Tracheid length, which is correlated with wood density, in roots is relatively constant from pith to bark, while tracheid length varies within boles and branches (Peterson et al. 2007). Although branch specific gravity is not affected by its distance from the bole (Woodcock and Shier 2003), the pattern of root wood compression strength decreasing with distance from the stem (Stokes and Mattheck 1996) may also hold for root wood density.

Roots are subject to different conditions and stresses than tree stems and branches, and therefore may exhibit different trends in wood density and C content. The C content of woody biomass has been shown to range from approximately 47 to 59 percent (Arola 1976, Fryling 1966, Hollinger et al. 1993, Pingrey 1979, Ragland 1991, Tillman 1981), but is generally assumed to equal 50 percent for both wood and bark (Cooper 1983, Dewar and Cannell 1992, Hollinger et al. 1993, Matthews 1993, Sedjo 1989, Thuille et al. 2000, Wenzl 1970). However, bark typically contains less carbon than wood relative to its density (Quilho and Pereira 2001).

Accurate wood density estimates depend on accurate volume measurements. For branches, volume can be estimated from path distances between set diameter intervals and summed for each branch (Sillett et al. 2010). The same method can be applied to roots, giving root taper information. The alternative volume estimation method of displacement (immersion in liquid) does not provide root dimension and taper information, which can be used to develop root volume and taper equations. These models would allow for subsampling during excavation and prediction of the biomass in missing/broken roots from diameter at the point of breakage.

The objective of this study was to quantify wood density and percent C at different locations within tanoak (*Notholithocarpus densiflorus* (Hook. and Arn.) Manos, Cannon and S.H. Oh) root systems. In addition to measuring the percent C, accounting for wood density gradients is likely to improve the accuracy of belowground biomass and C estimates (Nock et al. 2009). We hypothesized that (1) roots of larger diameter have both denser wood and a greater proportion of C and (2) wood within the lignotuber is most dense and holds proportionally the most C while roots decrease in wood density and proportion of C with increasing distance from the lignotuber. Root bark volume and C content were also examined. Results will support efforts to quantify belowground C storage and sequestration in the redwood region.

Methods

Site description

Root systems were excavated at the L.W. Schatz Demonstration Tree Farm, near Maple Creek, Humboldt County, California. The 148 ha tree farm is located 40 km inland and extends from N40º46'49" to 40º45'56" and W123º52'21" to 123°51'32". Average annual precipitation is approximately 120 cm with the majority falling as rain between the months of November and March.

Before clearcutting in the 1950s, the site was occupied predominantly by old-growth Douglas-fir (*Pseudotsuga menziesii*) forest with tanoak and California bay (*Umbellularia californica*). Species composition on the property now consists primarily of Douglas-fir, grand fir (*Abies grandis*), and tanoak mixtures, and pure stands of *Alnus rubra* (West 2007).

Excavation and measurements

Three second-growth tanoak trees were selected for sampling. Tree height, live crown base height, diameter at breast height (dbh), and diameter at the base of the tree were measured. An excavator was used to create a 30 cm wide trench at a distance of 1 m surrounding each tanoak to the depth where roots were no longer visible (approximately 1 m) severing the lateral roots traversing the trench. A rope was attached 5 to 10 m up the bole and each tree was pulled over using either a 4WD vehicle or a hand winch. We measured the diameter of the severed root ends and their distances from the lignotuber to allow for future prediction of mass lost during excavation (Niiyama et al. 2008).

Root samples were extracted at four locations within the root systems. Two pith-to bark wood cores were collected from each stump and lignotuber. Lateral roots oriented in the four cardinal directions around the three sample trees were excavated by hand for density and C analysis. Two short sections of root were cut from each lateral root: one adjacent to the excavated trench approximately 100 to150 cm from the stem, and a section of the same root at the narrow end farthest from the stem (*fig. 1*).

The green volume of these samples was estimated by measuring their diameter and length, and assuming the volume of each section was best represented by a truncated cone. Samples were dried at 65 °C and weighed to obtain dry mass. Much of the water was removed by drying biomass at 65 °C but drying at 100 °C was required to remove water bound within the cell walls (Wiemann and Williamson 2010). Different portions of the same roots used for C analysis were dried at 65 °C and weighed, and then dried further at 100 °C and re-weighed for comparison.

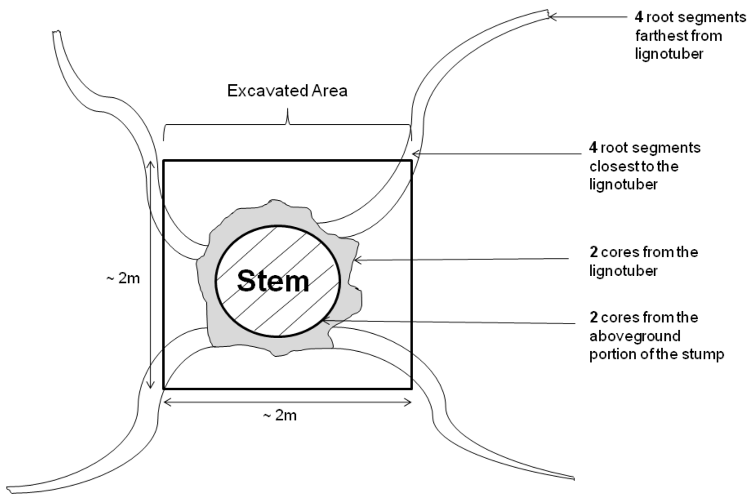

Figure 1—Locations and quantities of C samples within each of the three individual tanoaks excavated at the L.W. Schatz Demonstration Tree Farm.

Root bark samples collected throughout the three root systems were displaced in water to obtain estimates of bark volume. The estimates of volume and dried bark weight gave estimates of bark density. A subsample of root bark with known mass was removed and analyzed for percent C. A caliper was used to measure the outside diameter of roots including the bark and the diameter inside bark of roots with varying diameters giving estimates of the cross sectional area and volume of bark in lateral roots.

Carbon/nitrogen analysis

Percent C in each stump, lignotuber, root and bark sample was determined using a dynamic flash combustion system coupled with thermal conductivity/ IR detection (Thermo-Finnigan Flash EA 1112). Samples were oxidized by flash combustion which converted all organic and inorganic substances into combustion gases (N_2, NO_x, CO_2, and H_2O). The method has a detection limit of approximately 0.1 percent for C (http://anlab.ucdavis.edu/analyses/plant/sop522[2], AOAC Official Method 927.43).

Statistical analysis

We constructed a nested model to test for differences in wood density and percent C at the different locations within the root system across all sample trees. Tukey-Kramer’s multiple comparison test was used to identify differences among the sample locations and the acceptable level of error was adjusted for multiple comparisons ($\alpha = 0.008$). One-way ANOVA was used to identify differences in root wood density and percent C within and between trees. Additionally, density and percent C were regressed against the sample locations’ path lengths from the lignotuber using Minitab 16 Statistical Software (Minitab 2010).

[2] Total nitrogen and carbon – combustion method. University of California, Davis, analytical lab.

Results

The sample trees were similar in height, but had different stem diameters and crown ratios and occupied different positions within the canopy (*table 1*).

Table 1—*Aboveground sample tree data for tanoak at L.W. Schatz Tree Farm.*

Tree	Height (m)	Live crown ratio	Dbh (cm)	Diameter at base (cm)	Crown position
1	21.1	0.81	33.5	39.6	open grown/dominant
2	18.3	0.27	34.8	42.1	codominant
3	20.7	0.59	52.4	60.1	codominant

Mean wood density for belowground components (lignotuber, lateral roots) was 590.3 kg/m^3 and varied between 565 and 621 kg/m^3 (*table 2*). The nested model with trees as random factors indicated that no significant difference in root wood density among trees ($p = 0.508$), or among sample locations ($p = 0.334$) was detected (*fig. 2A*). Wood density did not change when regressed against root diameter ($F = 1.16$, $p = 0.260$) nor path distance from the lignotuber ($F = 0.04$, $p = 0.852$) but was highly variable among trees (coefficient of variation = 0.139).

The grand mean of the C samples across the three trees was 49.5 percent. The nested model indicated that no significant differences in percent C among trees were detected ($p = 0.097$), but percent C differed among sample locations ($p < 0.0001$). Kramer-Tukey multiple comparison tests indicated that sections of roots farthest from the lignotuber had a significantly greater C content than the other sample locations while the aboveground stump, lignotuber and the samples nearest the lignotuber were not significantly different in percent C (*fig. 2B*). Mean percent C ranged from 48.6 to 50.6 percent (*table 2*).

Percent C did not change when regressed against diameter ($p = 0.703$). A nested model of belowground percent C (stump C not included) with individual trees as a random effect indicated that percent C increased with path distance from the lignotuber ($p = 0.003$) (*fig. 3*). The model explained 45 percent of the variation in belowground percent C which varied within and between sample trees (coefficient of variation among trees = 0.02).

Mean root mass decreased 5.5 percent when the drying temperature increased from 65 °C to 100 °C. The proportion of root volume comprised of bark was consistent for all root diameters (mean proportion bark volume = 22.1 percent) and bark consisted of 48.6 percent C.

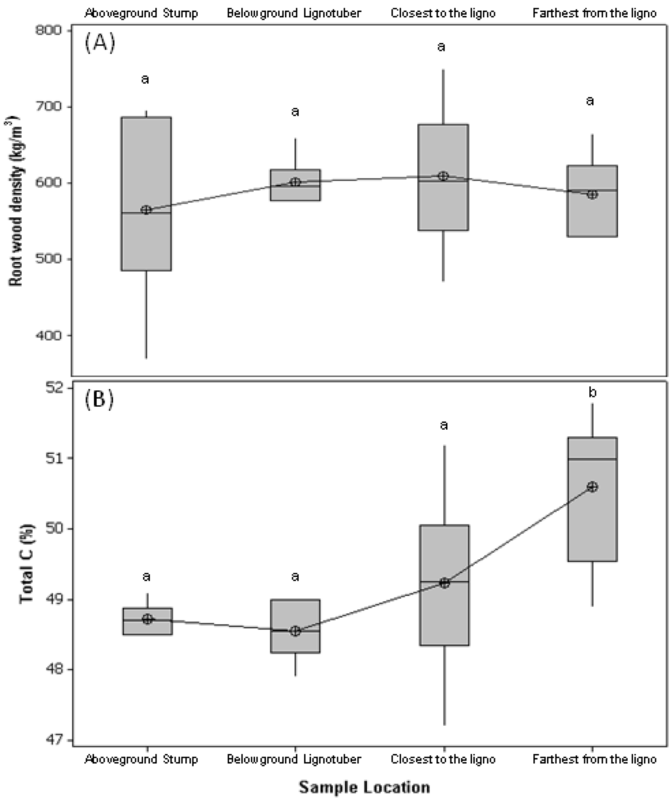

Figure 2—Box plot of (A) wood density and (B) percent C at the different sample locations in the root system. Different letters indicate significant differences in percent C and wood density. Lines connected by location means.

Table 2—*Root wood density and percent C for the three sample trees. Differences in location means detected by Tukey-Kramer multiple comparison tests indicated by different letters. Acceptable levels of error adjusted for multiple comparisons (α = 0.008).*

		Wood Density (kg/m^3)		
Tree	stump	lignotuber	near	far
1	635.7	628.3	648.7	507.8
2	529.5	590.8	614.2	526.5
3	592.3	585.7	564.9	662.9
mean	585.9^a	601.6^a	621.2^a	565.7^a
st. dev.	52.4	30.7	87.0	105.5
max	664.9	659.7	749.4	696.5
min	528.4	575.6	471.2	370.0
		Total C (%)		
Tree	stump	lignotuber	near	far
1	49.0	49.0	50.6	51.3
2	48.7	48.3	49.1	50.2
3	48.5	48.4	48.0	50.3
mean	48.7^a	48.6^a	49.2^a	50.6^b
st. dev.	0.2	1.4	1.2	1.1
max	47.3	51.1	51.8	51.4
min	48.5	47.3	47.2	48.5

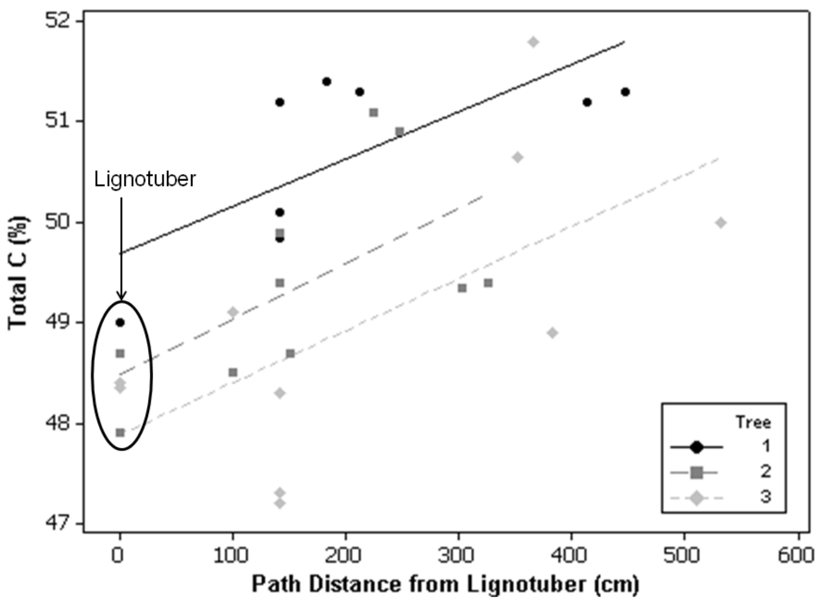

Figure 3—Change in C with increasing path length from the lignotuber. Lignotuber included as zero distance.

Discussion

The grand mean root wood density of 589.58 kg/m^3 was almost equal to the value of 580 kg/m^3 reported in the Global Wood Density Database for tanoak in North America (http://datadryad.org/handle/10255/dryad.235, Alden 1995) even though latitude, temperature and precipitation (Wiemann and Williamson 2002), successional stage (Henry et al. 2010, Wiemann and Williamson 1988, Woodcock and Shier 2002), stocking levels (Persson et al. 1995), and diameter distribution (Ruiz-Jaen and Potvin 2010) typically contribute to variation in wood density across forests. The differences in root wood density and percent C between trees was not surprising considering individuals of the same species often exhibit large within-stand variation due to genetic variation (Fries and Ericsson 2009, Wang et al. 2000, Zhang and Morgenstern 1995) and canopy position (Aiba and Nakashizuka 2009, King and et al. 2005). The variations in root wood density between different sample sections within each sample tree was a concern, and suggests that great care must be taken when measuring green root dimensions for volume estimates. The large differences in root wood density between different sample trees indicated that a large sample size is needed to obtain precise estimates of belowground biomass in tanoak at the stand level (*table 2*).

The increase in C and absence of detectable change in wood density with distance from the lignotuber is contrary to aboveground findings that wood density decreases with increasing stem height (Correia et al. 2010, Park et al. 2009, Paul et al. 2008). Larger diameter roots containing more biomass did not have greater wood density or percent C (*table 2*), suggesting that root systems allocate C differently than aboveground stems. Our finding that wood density does not increase with larger diameter roots also suggests that tanoak roots may not develop juvenile wood. Peterson et al. (2007) reported that juvenile wood was absent in roots and that roots have a relatively high density at a low cambial age (ring number from the pith). This contradicts the common assumption that the cambium is constrained to produce short cells when it is young and after a certain period of time produces denser wood. Because roots, branches and stems have different mechanical and physiological functions, it is not safe to assume that above- and belowground components allocate C in the same way.

Modeling percent C as a function of the continuous variable 'path distance' from the lignotuber (*fig. 3*) will allow us to make better predictions of belowground C mass in tanoak. Given that most of the belowground biomass is centrally located near the stem, summing C estimates for discrete sections of roots with different C content will give more accurate estimates at the tree level than if the grand mean of 49.5 percent C content was applied to estimates of total root system biomass.

Conclusions

Root wood density was highly variable within and between trees, but remained approximately constant on average with increasing distance from the lignotuber. Percent C did not remain constant throughout tanoak root systems. Accounting for density and C differences throughout the root system will allow for more accurate estimation of belowground C.

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