**Estimating felled-tree stump volumes in the Pacific Northwest**

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**Introduction**

Pacific Northwest forest land managers seek estimates of post-harvest woody residues to meet a variety of land management objectives, including characterizing woody biomass, lifecycle, and carbon accounting. Stumps of felled trees can be a significant source of woody biomass remaining in forest stands after timber harvest. Land managers need the ability to accurately estimate stump volumes and biomass with the use of standard inventory variables, such as diameter breast height (DBH).

National biomass component ratio protocols (Woodall et al. 2011) specify the use of the Raile (1983) taper equations to estimate stump diameters and cubic volume (above ground) based on tree DBH and stump height. Woodall et al. (2011) provide species-specific parameters for use with the Raile equations, including Douglas-fir, the most commonly grown species in the Pacific Northwest. The Raile equations have been shown to be highly accurate for estimating the volume and diameter of eastern U.S. hardwood and conifer stumps (Barker 2017). However, little effort has been made to develop taper equations for characterizing western U.S. Douglas-fir stumps and volumes. Western taper functions may prove superior to Raile for estimating these attributes.

**Objective:** Identify an existing DBH-based taper function that accurately estimates young-growth Douglas-fir above-ground stump volumes outside bark in the Pacific Northwest.

**Methods**

**Overall approach.** We compared above ground stump volumes computed with three different taper functions with “true” stump volumes calculated with Douglas-fir stump diameters and heights and estimated ground-level diameters measured by the University of Montana’s Bureau of Economic and Resource Research (BERER).

**Sampling.** The BERER’s logging utilization research (see Simmons et al. 2014 and 2016) provided records of 1,481 second and third growth Douglas-fir felled trees measured 2011–2013 within 110 commercial logging sites (generally 15 to 29 Douglas-fir trees per site) in Idaho, Montana, Oregon, and Washington. Individual tree measurements included outside bark felled tree stump height and diameter and tree DBH.

**Estimating ground-level stump diameters.** Accurate estimates of ground-level stump diameters were needed for all sampled trees to calculate “true” stump volumes. Three DBH-based taper functions were evaluated as ground-level stump diameter estimators against field-measured diameters of 45 Douglas-fir stump samples ranging 0.6 to 1.2 feet in height. We assumed that a taper function could accurately predict diameters for these short stumps if it could also accurately predict diameters at ground level. Lin’s (1989) concordance correlation coefficient was used to evaluate taper equation estimation accuracy. The three DBH-based taper functions included Raile and two functions developed for western North America sites:

- **Raile (1983):** \(d = DBH \times DBH^{-1} \times e^{(4.5-0.1267/DBH)}\) D. Douglas-fir coefficient = 0.1267. Developed for northeastern U.S. stump diameter and volume estimation; coefficients provided by Woodall et al. (2011) for all U.S. tree species.

- **Demaerschalk and Omule (1982):** \(d = DBH(1 + 1.276/DBH^{1.276})\) D. Douglas-fir coefficient = 0.04302. This is a better DBH taper function developed for Douglas-fir in northern California.

- **Wensel and Olson (1995):** \(d = DBH^{(0.68/DBH^{0.68})}\) D. Douglas-fir coefficient = 0.04302. This is a better DBH taper function developed for Douglas-fir in northern California.

**Note:** \(d\) = Douglas-fir coefficient; \(d\) = stump diameter outside bark; \(e\) = exponential function; \(h\) = stump height of interest; \(n\) = natural logarithm.

**Estimating stump volumes from the taper functions.** The three taper functions were also used to estimate cubic volumes of stumps by integrating the functions using the standard rules of revolution procedures.

**Results and Discussion**

**Ground-level stump diameter estimates.** The Wensel and Olson equation provided superior estimates of ground-level diameters with the highest concordance correlation coefficient of 0.9562 (Figure 1). These estimated ground-level diameters were used with measured stump attributes to calculate “true” stump volumes.

**Stump volume estimates.** At integrated taper function stump volumes were strongly related to the measured “true” volumes in PROCG MIXED multilevel regressions (Figure 2, the Wensel and Olson function serving as an example, all functions displayed similar plots). All accuracy measures - Akaike’s Information Criteria (AIC), root mean squared error (RMSE), and absolute bias - demonstrated that the integrated Wensel and Olson equation was the most accurate estimator of Douglas-fir above ground stump volumes among the three taper functions (Figure 1).

**Application**

**Recommended taper function.** The Wensel and Olson function can be used to accurately predict below bark volumes of young-growth Douglas-fir stumps in the Pacific Northwest.

**Calculating stump volumes.** Above ground cubic foot volume can be calculated by multiplying the Wensel and Olson integrals (table 1) by basal area at crown level. Example volumes have been calculated for stump diameters ranging from 0.6 to 1.2 feet in height for a 1-0 inch DBH Douglas-fir tree (table 1). Basal areas of Douglas-fir trees of any DBH can be used to calculate stump volumes. The authors can provide integrals for any stump height of interest.

**Estimating stump biomass and carbon content.** Land managers can apply similar rules and coefficients found in Woodall et al. (2011) to calculate stump biomass and carbon content from stump volumes to estimate biomass and carbon content of the stump’s bark and wood components.

**References**


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