On the Variation of Inventory Estimates for Redwood Stands[1]

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Abstract

There is a tremendous amount of variation in the second growth redwood (*Sequoia sempervirens* (D. Don) Endl.) forests found along the North Coast of California. In order to make prudent management decisions about these forests, foresters and other resource professionals often conduct timber cruises to collect information on tree species, diameters, tree heights, crown ratios, bole taper, and other variables of interest. When designing point sample timber cruises to collect these data, it is important not only to consider sample size (the number of point samples), but to also consider how frequently to subsample trees for volume measurements. The purpose of this paper is to report on a study where Green Diamond simultaneously assessed the effects of both of these key timber cruise design elements on confidence intervals for board foot volume estimates.

Keywords: confidence interval, point sampling, timber cruise, volume estimate

Introduction

Second growth redwood (*Sequoia sempervirens* (D. Don) Endl.) stands commonly found along the North Coast of California can exhibit a tremendous amount of variation under certain stand and site conditions. These stands were usually naturally regenerated following the harvest of the old growth timber and, as a result, typically contain a diverse mix of conifer and hardwood species. Many of these second growth stands were then subjected to partial harvesting operations on multiple occasions to remove overstory trees depending on log markets and the owner's objectives. Natural conifer regeneration following such entries was inconsistent and often hindered by brush and hardwood competition. Further complicating the situation is the presence of sprouting species, such as redwood and tanoak, which lead to a great deal of variation within the stand with respect to the spatial arrangement of the trees. As a result, it can be a challenging exercise coming up with reliable cost-effective inventory estimates.

In this paper, the focus is on a redwood/Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stand that has all the challenges mentioned above. The stand is located in Humboldt County approximately 14.5 km (9 miles) east of the city of Eureka, California, at 40°47'17"N 123°59'5"W. It was naturally regenerated following the removal of the old growth resource. Then, the second growth resource was partially removed in multiple harvesting operations. Today the stand has a diverse range of tree species, size classes, and age classes haphazardly scattered over the landscape. It is an inventory forester's nightmare.

In order to manage the stand for timber production, Green Diamond requires current inventory information. There is a need to have information on species composition, volume by diameter class, tree ages, and site index. To collect these data, foresters rely on point sample timber cruising. However, given the heterogeneity of this stand, how should a timber cruise be designed? How many point sample plots should be included in the cruise so that acceptable confidence intervals can be constructed? Is it appropriate to consider using a mix of volume plots and count plots and, if so, what should be the ratio between volume plots and count plots? Alternatively, should volume trees be subsampled on each sample point and, if so, to what extent should subsampling occur? The objective of this study was to address such questions by examining confidence intervals and the margin of error

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for board foot (bd ft) volume estimates and how these statistics are affected by sample size and subsampling of volume trees.

Data Collection

The stand selected for this study was 64.7 ha (160 ac) in size. One of the objectives was to examine timber cruise statistics over a wide range of sampling intensities. A 76.2 m x 76.2 m (250 ft x 250 ft) grid was overlaid on the stand that resulted in 93 sample points (see fig. 1).[3] A sample size of 93 is extremely large for a 67.4 ha (160 ac) stand, and is more than enough to examine how volume estimates and their confidence intervals "stabilize" as sample size increases.

To estimate basal area per acre, the timber cruise was conducted using a Basal Area Factor[4] (BAF) of 62.5.[5] With a 62.5 BAF, each "in" tree at a sample point represents 62.5 sq ft of basal area. Every "in" tree was measured for height and diameter so its bd ft volume could be calculated using equations in Krumland and Wensel (1978) for conifers or Naccarini et al. (1979) for hardwoods.

Then, to study the impact of subsampling volume trees, the timber cruiser then determined which trees would be "in" using three additional, bigger BAFs: 184.29, 250, and 360. The mathematics of point sampling is such that as the BAF is increased the probability of a tree being "in" is decreased. Thus, the number of volume trees goes down as the BAF increases from 184.29 to 360. Using a bigger BAF to subsample volume trees is known as the "big BAF method" (Marshall et al. 2004). The big BAF method is used extensively throughout the Pacific Northwest when designing and conducting timber cruises. Under some circumstances, the method can be more efficient than cruise designs that call for volume measurements on 100 percent of the "in" trees (Marshall et al. 2004).

Another popular method for subsampling volume trees is to skip the volume measurements on some of the sample points. For example, the cruise design might specify that the timber cruiser only measure volume trees on every other plot, every third plot, or even every fourth plot—so called 'volume plots'. With the data set collected as specified above for this study, such an analysis is easily conducted by simply ignoring the volume measurements on some of the plots and analyzing them as 'count plots'.

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[3] Volume information was desired for that portion of the stand outside of watercourse buffers so sample points were intentionally omitted in those areas.

[4] Point sampling utilizes devices to project critical angles that determine which trees are "in" or "out". The critical angles are selected such that each "in" tree represents a predetermined basal area per acre, which is known as the Basal Area Factor (BAF). Readers interested in reviewing point sampling basics should consult a textbook such as Avery and Burkhart (2002).

[5] Using a 62.5 BAF for this project resulted in an average of 4.4 trees per sample point. This number is acceptable but it is at the low end of the target range of four to eight trees per sample point.

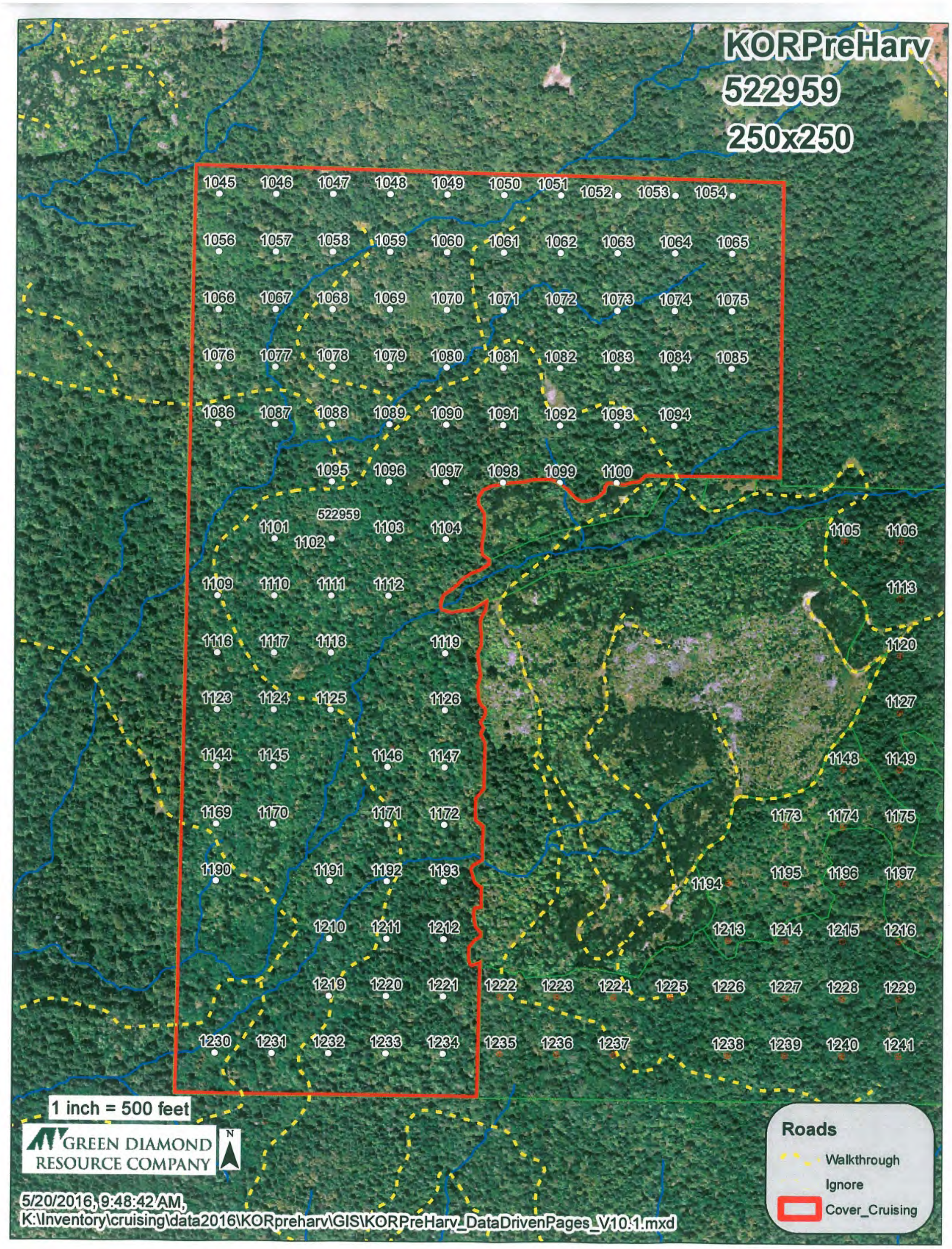

Figure 1—Aerial photograph showing the stand boundary (red lines) and the location of the cruise sample points.

Data Analysis

The timber cruise data were compiled using the variable probability sampling procedures described in Dilworth and Bell (1982). Briefly, the volume per acre is estimated as the average volume to basal area ratio (VBAR) times the average basal area (BA) per acre. That is:

$$\text{Volume per acre} = \text{VBAR} \times \text{BA per acre}$$

Dilworth and Bell (1982) also describe how to calculate standard errors (a) when all plots are volume plots (i.e., all trees on all sample points are measured for volume), and (b) when both count plots and volume plots are specified in the cruise design. Marshall et al. (2004) explain that the same formulas in Dilworth and Bell (1982) can be used to estimate volume per acre and calculate standard errors for the big BAF method.

Results

All Trees Measured for Volume

A unique way to display the results for this timber cruise (or any timber cruise for that matter) is to show what happens to the estimate of volume per acre and the confidence limits as sample size is increased from 2 plots to 93 (fig. 2). A confidence limit (CL) is either of the extreme values of a confidence interval.

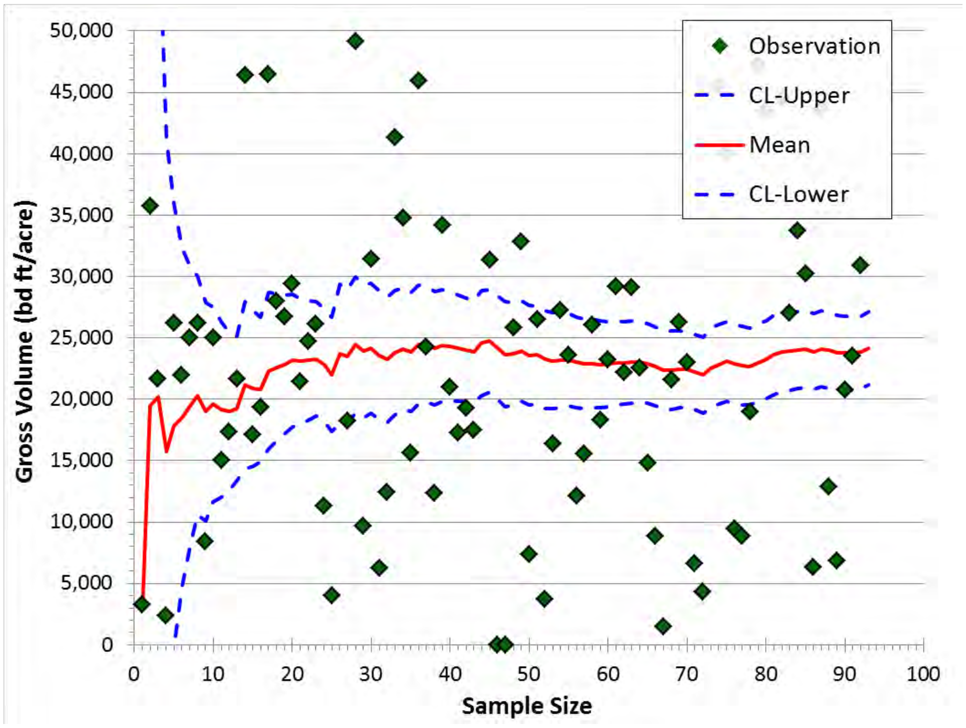

Figure 2—Estimates of mean bd ft volume per acre (red line) and associated upper and lower confidence limits (blue dashed lines) as sample size is increased from 2 plots to 93 plots. For each sample point all the trees where regarded as volume trees and used to calculate the mean and confidence limits. Note the tremendous variation associated with the plot data (green diamonds). Volume per acre varies from 0 bd ft per acre up to 50,000 bd ft per acre.

Rather than plotting the mean and confidence limits, another way to look at these same data is to plot the margin of error. The margin of error is

$$\text{margin of error} = \frac{\text{t value} \times \text{standard error}}{\text{mean}}$$

The t value x standard error is ½ the width of a confidence interval. As you can see, the margin of error is a percentage of the mean. Figure 3 is a chart showing the margin of error for the data shown in fig. 2.

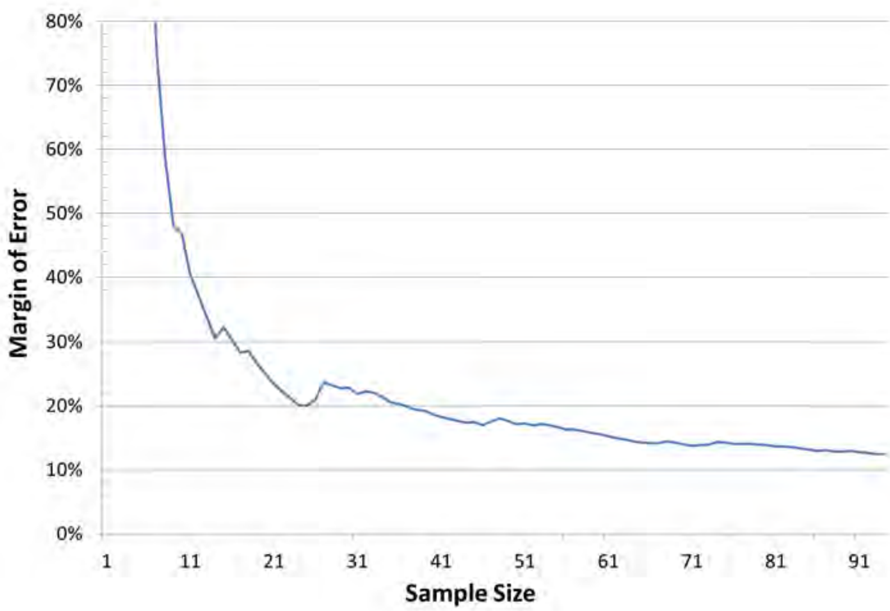

Figure 3—Illustration of how the margin of error decreases as sample size increases. The margin of error is calculated by dividing ½ the width of the confidence interval by the mean bd ft volume per acre. At the risk of being redundant, this chart is just a different way of looking at the same data shown in fig. 2.

The margin of error decreases rapidly as sample size increases from 2 plots to 30 plots. After 30 plots, the margin of error decreases gradually. This pattern is not unexpected. The margin of error is a function of the t value and the standard error, and both of these values decrease as sample size increases.[6]

To recap, figs. 2 and 3 were constructed using all the trees on the plots that were determined to be "in" using a BAF of 62.5 as volume trees. Next, I am going to look at what happens to the margin of error when trees are subsampled for volume measurements. Subsampling should increase the margin of error because fewer volume trees are used in the computation of the standard error. For specifics on calculating standard errors for point sample data, the interested reader should consult Dilworth and Bell (1984) pages 56 to 62.

[6] If you inspect a t table, you will see that t values strictly decrease as the degrees of freedom increases. (Note that degrees of freedom = sample size – 1.) Standard errors, on the other hand, generally decrease as sample size increases.

Impact of Subsampling Volume Trees by Utilizing Count Plots

To assess the impact of utilizing count plots on the margin of error, the 93 plots were segregated into volume plots and counts plots. Four scenarios were analyzed:

Scenario label	Volume plots	Volume plots (%)	No. of volume trees
BAF 62 VOL25%	1 out of 4	25%	126
BAF 62 VOL50%	2 out of 4	50%	228
BAF 62 VOL75%	3 out of 4	75%	313
BAF 62 VOL100%	4 out of 4	100%	412

Margin of error curves for each of these scenarios are shown in fig. 4. It should be noted that the 4th scenario (BAF 62 VOL 100 percent) was already presented in fig. 3. It is included in fig. 4 so the impact of subsampling can readily be compared to the scenario where all the trees are used in the calculation of volume per acre means and standard errors.

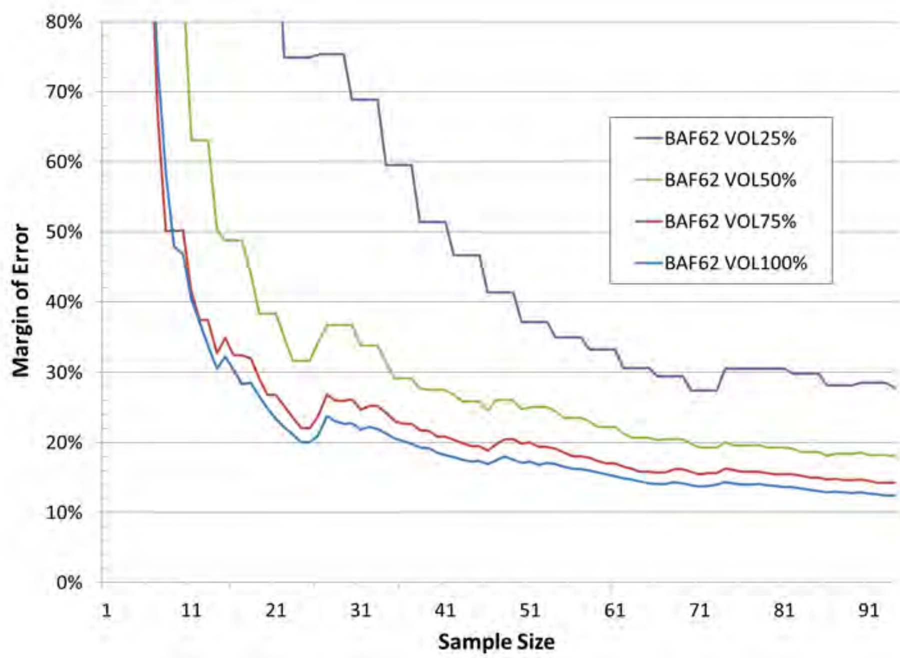

Figure 4—This chart shows the impact of utilizing count plots on the margin of error. The BAF62 VOL100 percent curve is based on all volume plots and the other curves are based on different ratios of volume plots to count plots.

The impact of subsampling volume trees by utilizing count plots in the cruise design is readily observable in fig. 4 for the redwood/Douglas-fir stand featured in this study. For example, if the goal is to obtain a margin of error that is +/– 20 percent of the mean, then that level of precision cannot be achieved with a sample size of 93 plots utilizing a sampling design where one in four plots is a volume plot. On the other hand, +/– 20 percent can be achieved with approximately 30 plots if every plot is a volume plot. If two out of four are volume plots, then the +/– 20 percent margin of error can be achieved with approximately 65 sample plots.

Impact of Subsampling Volume Trees by Utilizing the Big BAF Method

To assess the impact of utilizing the big BAF method on the margin of error, data from the 93 plots were analyzed using a selection of big BAFs to determine which trees to measure for volume. Four scenarios were analyzed:

Scenario label	Big BAF	Basal area BAF	No. of volume trees
BAF 360	360	62.5	81
BAF 250	250	62.5	119
BAF 184	184.29	62.5	162
BAF 62	62.5	62.5	412

Margin of error curves for each of these scenarios are shown in fig. 5. It should be noted that the 4th scenario (BAF 62) was already presented in fig. 3. It is included in fig. 5 so the impact of subsampling (on the margin of error) using the big BAF method can readily be compared to the scenario where subsampling is not utilized.

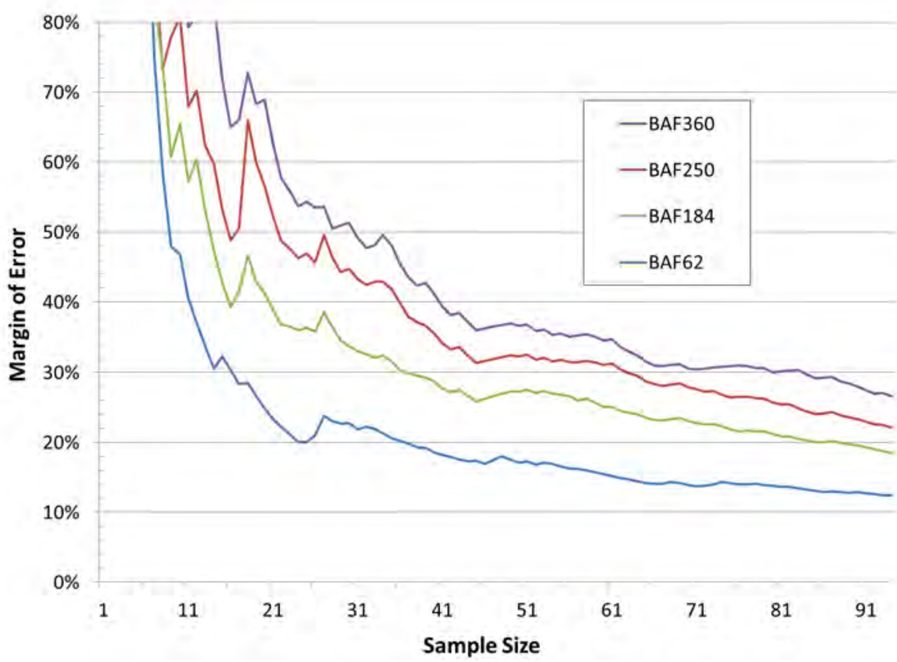

Figure 5—The chart shows the impact of utilizing the big BAF method to subsample volume trees on the margin of error. The BAF62 curve considers all trees as volume trees whereas the other curves subsample volume trees by using a BAF larger than 62.5.

The impact of subsampling volume trees by utilizing the big BAF method in the cruise design is readily observable in fig. 5 for the redwood/Douglas-fir stand featured in this study. For example, if the goal is to obtain a margin of error that is +/– 20 percent of the mean, then that level of precision cannot be achieved with a sample size of 93 plots utilizing a big BAF of 250 or 360. Utilizing a big BAF of 184.29, it takes a sample size of approximately 85 plots to achieve a precision of +/– 20 percent. On the other hand, if every tree is measured for volume +/– 20 percent can be achieved with approximately 30 plots.

Conclusion

Subsampling volume trees can save a forester a lot of time and money under certain stand and site conditions. Two examples are given in Marshall et al. (2004): a Douglas-fir stand near Corvallis, Oregon, and a Jeffrey pine (*Pinus jeffreyi* Balf.) stand near Lake Tahoe, California. In those examples, the population of volume trees exhibited very little variation in cu ft volume to basal area ratios (VBARs). For the redwood/Douglas-fir stand featured in this study, the bd ft VBARs varied by species and within species[7] and as a result, subsampling volume trees had a huge impact on standard errors and confidence intervals.

Based on the results obtained in this study, it is recommended that inventory foresters take the time and effort to understand the impact of subsampling volume trees on the standard errors and confidence intervals for the various stand and site conditions under their management. This is particularly true for foresters who work in the naturally regenerated second growth stands commonly found along the North Coast of California. Under certain stand and site conditions, it may be more efficient to take volume measurements on every tree but put in fewer sample points (see figs. 4 and 5) to achieve the desired precision. On the other hand, for redwood stands that are relatively uniform (such as intensively managed third growth) a cruise design that specifies subsampling volume trees may be a more appropriate choice. Foresters interested in subsampling the optimal number of volume trees should consult Marshall et al. (2004) for the appropriate equations and methodology.

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[7] Interested readers should contact the author for more details regarding the VBARs for the redwood/Douglas-fir stand featured in this study.