SIMULATION OF DESIGN-UNBIASED POINT-TO-PARTICLE SAMPLING COMPARED TO ALTERNATIVES ON PLANTATION ROWS

Thomas B. Lynch, David Hamlin, and Mark J. Ducey[1]

Total quantities of tree attributes can be estimated in plantations by sampling on plantation rows using several methods. At random sample points on a row, either fixed row lengths or variable row lengths with a fixed number of sample trees can be assessed. Ratio of means or mean of ratios estimators can be developed for the fixed number of trees option but are not design-unbiased. Ducey's estimator samples a fixed number of trees and is design-unbiased, as is sampling fixed row length. Simulations indicted that some of the ratio estimators could have substantial bias on rows containing large gaps, but for other ratio estimators bias was minimal in practical terms. Ducey's method is unbiased but had a root mean square error slightly larger than some of the ratio estimators.

Ducey (2012) suggested a method of selecting a fixed number of sample trees on a line that is design-unbiased. Borders and others (2012) proposed plantation row sampling, in which plantation rows would be sampled by using either a fixed-length plot or a fixed number of sample trees per sample location. Total row lengths in plantation row sampling are determined by remote sensing methods. Ground-based sampling is used to determine attributes such as number of trees and volume per lineal foot of row. Totals are then obtained by multiplication with row length. The fixed number of sample trees method proposed by Borders utilized ratio estimators that are not design–unbiased, though they may have low bias in practice. Ducey's (2012) method of design-unbiased point-to-particle sampling on lines can be combined with Borders' idea of plantation row sampling to obtain design-unbiased estimates with a fixed number of sample trees per sample location on the row.

Here we compared design-unbiased point-to-particle sampling on plantation rows to five alternative methods using computer simulation. Design unbiased point-to-particle sampling applied to plantation rows samples a fixed, even number of trees on a row for each randomly-located point on a plantation row. One simple alternative is sampling the trees on a fixed length of row for each randomly-located point on a row. Other alternatives include methods which measure the length of row occupied by a fixed number of trees for each randomly located point on the row either including or excluding the "sample gap" into which the random sample point falls. We examined four ways to do this: G-MR is a mean of ratios estimator including the sample gap, G-RM is a ratio of means estimator including the sample gap, NG-MR is a mean of ratios estimator that does not include the sample gap, and NG-RM is a ratio of means estimator that does not include the sample gap. We simulated plantation rows for two scenarios – one including substantial gaps similar to those that might arise from thinning and/or mortality, and another that does not include such gaps which might resemble a younger unthinned plantation. Results were obtained for fixed-tree number designs that have an even number of trees from 2 to 12 and for fixed-length plots that have similar expected numbers of trees per plot.

Each of the estimators was tested on two simulated row populations. We included a fixed-length row estimator designed to sample a mean of $2k$ trees. Estimators having numbers of sample trees $2k$ ranging from 2 to 12 were tested. One population was a "Not Gappy" (NG) row with a target length of 100,000 feet and a mean inter-tree distance of 6 feet ranging from 3.6-7 feet, having a total of 16,667 trees. The other population was "Gappy" (G) with a target length of 100,000 feet, mean inter-tree distance of 9 feet and a standard deviation inter-tree distance of 7.4 feet with inter-tree distances ranging from 3.6 feet to 59.9 feet and a total of 11,109 trees on the row population. For each population and each method, bias percent and Root Mean Square Error percent (RMSE%) was simulated for an estimator having n=10 row locations. Exact bias and variances could be calculated for Ducey's method and the Mean of Ratios (MR) methods. For the Ratio of Means estimators (RM) 1 million simulations were performed using an R (R Core Team 2014) simulation program.

The results indicated that the G-MR and the NG-RM had the best Root Mean Square Error percent (RMSE%).On the G row, the G-RM and the NG-MR were biased significantly. The fixed-length plot is design-unbiased and so did not show bias in the simulations. It performed well in RMSE% but not as well as some

[1]Thomas B. Lynch Department of Natural Resource Ecology and Management, Oklahoma State University, Stillwater, OK 74078
David Hamlin Campbell Global, One S.W. Columbia Suite 1700, Portland, OR 97258
Mark J. Ducey Dept. Natural Resources, University of New Hampshire, 215 James Hall, Durham, NH 03824

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of the other methods. Ducey's method showed slightly higher RMSE% than some of the alternative methods but is design-unbiased and so unbiased for any spatial distribution including the G and NG simulation rows used here.

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