Simulating and Sampling the Hardwood Component of Loblolly Pine Plantations

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Abstract. The hardwood component of young loblolly pine (*Pinus taeda* L.) plantations was simulated for use in a sampling study of competing vegetation. Spatial arrangement, total height, and crown area of hardwood rootstocks in 19 plantations 3 to 6 years old in Alabama and Georgia were used to develop the simulator. Rootstock arrangement ranged from uniform to clumped. A two parameter, left- and right-truncated Weibull function modelled height distribution. Total rootstock height conditionally determined crown area. The simulator was used to evaluate 42 sampling estimators of competing hardwood vegetation. Bias, precision, and variance of the estimators were compared. All estimators were relatively unbiased at low sampling intensities. Rootstock clumping reduced precision and increased variance. Variable plot estimators exhibited greater precision and lower variance. Horizontal variable plot estimators are recommended for use in quantifying the amount of competing hardwood vegetation in young loblolly pine plantations.

Introduction

An estimated 25.3 million acres of commercial timberland in the southern United States is occupied by southern pine plantations. This acreage is expected to increase. Control of competing hardwood and herbaceous vegetation present in these plantations has a positive effect on growth and yield of pine. Forest managers need accurate information regarding the level of competing vegetation in order to evaluate the need for or type of vegetation control. Few sampling methods have been rigorously tested to determine their ability to provide the necessary information for vegetation control decisions. The information required for

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these decisions includes (1) the amount of competing vegetation present and (2) the impact of competing vegetation on growth. This paper describes a simulation model of potentially competing hardwood vegetation and a study to evaluate sampling estimators of the amount of competing vegetation present. Growth impacts are not discussed.

Simulating hardwood rootstocks

For this study, a hardwood rootstock was defined as all stems of the same species arising from a common point within 2 inches of the soil surface. Three attributes of hardwood rootstocks were simulated in this study: spatial arrangement (pattern), total height, and crown area. Spatial arrangement of objects can affect sampling estimators; however, the spatial arrangement of hardwood rootstocks was unknown. Total height and crown area were simulated because they appear to provide a measure of competitive stress. Nineteen loblolly pine (*Pinus taeda* L.) plantations in the Alabama and Georgia Piedmont were sampled to provide spatial pattern, total height, and crown area data to develop the simulator.

Spatial pattern

A computer program originally developed to produce a range of point patterns for use in tree harvesting studies (Newnham 1968) was modified to efficiently produce point patterns modelling the spatial pattern observed in the study plantations. Spatial pattern was quantified with Pielou's nonrandomness index α (Pielou 1959; Mountford 1961). α is used to predict variables that control location of generated rootstocks. Weise and Glover (1988) describe in detail the modifications made and the procedures used to produce point patterns. The modifications (1) reduced execution time by a factor as great as 80, and (2) permitted reproduction of point patterns within approximately 10 percent of the input value of α.

Total height

In nature, all hardwood rootstocks exert competitive stress on loblolly pine. However, the stress exerted by relatively small rootstocks on larger pines is minimal. Thus, minimum height limits were imposed during field sampling. A minimum height of 2.0 feet was used in plantations with mean pine total height of less than 4.5 feet, and a minimum height of 4.5 feet was used in plantations with mean pine total height greater than 4.5 feet. The Weibull distribution has been used extensively in forest growth and yield modelling—primarily in characterizing diameter distributions. It was used in this study because of its flexible shape (Bailey and Dell 1973). Data were separated into 4 sets—one each for stand ages of 3, 4, 5, and 6 years after plantation establishment. Since total height field data were truncated, the two-parameter, left- and right-truncated Weibull distribution was fit using WEIBUL (Zutter et al. 1982). The Kolmogorov-Smirnov test was used to compare each fitted distribution with field data; no significant deviations occurred. Each fitted distribution was inverted:

$$THT = b[(t/b)^c - \ln(1 - \{1 - \exp[(t/b)^c - (T/b)^c]\}\, FX)]^{(1/c)} \qquad [1]$$

where THT is total rootstock height, b and c are scale and shape parameters, t and T are left and right truncation points, and FX is a random number representing the cumulative relative frequency of THT. Total height could thus be simulated using a uniform random number generator.

Crown area

Crown areas were calculated using perpendicular crown diameters and the formula for the area of an ellipse. In order to keep a short hardwood rootstock from being assigned an unrealistically large crown area, crown area was conditionally determined by total height in the following manner. Empirical cumulative relative frequencies of crown area were developed for each total height class (2.5 to 20 feet, in 0.5-foot classes). Crown area was fit to cumulative relative frequency using least squares analysis by height class. Parameter estimates were then treated as dependent variables individually and regressed against total height.

Crown area is thus determined using a series of four equations. A uniform random number determines total rootstock height (THT) using equation 1. Total rootstock height then determines b_0 and b_1 using equations 2 and 3. These equations accounted for most of the variation in b_0 and b_1. A second uniform random number is drawn and equation 4 determines crown area:

$$b_0 = 0.162712 + 0.027227\, THT^{2.5} \qquad [2]$$

$$b_1 = -0.771563 + 0.953283\, THT^{1.5} \qquad [3]$$

$$Y = b_0 + b_1 X \qquad [4]$$

where THT is total rootstock height b_0 and b_1 are parameter estimates, X is a uniform random number representing cumulative relative frequency of crown area, and Y is crown area.

At present the simulator can produce point patterns ranging from uniform to heavily clumped. With further equation development, this range can be expanded. The versatility of Newnham's (1968) original program allows production of a wide variety of point patterns. The behavior of pattern indices as a function of the underlying spatial pattern can be studied more efficiently using the modified generator.

Sampling hardwood rootstocks

The effects of spatial pattern on sampling estimators has been examined (e.g., Oderwald 1981). However, no studies involving the sampling of competing hardwood vegetation were found in the literature.

Methods

To simulate operational sampling levels, we used low sampling intensities (1, 2.5, and 5 variable plots per acre, or a 1 percent sample for fixed-area methods). Table 1 lists the sample methods examined. The triple distance technique developed in New Zealand is described in Warren and Batcheler (1979). Each sampling method was tested using several different rules. For example, the horizontal point method was tested in the following configurations for a total of six rules: 100 CAF (crown area factor) at 1, 2.5, and 5 sample units per acre, and 200 CAF at 1, 2.5, and 5 sample units per acre. A total of 42 sample rules were evaluated.

Simulated rootstock populations exhibiting a wide range of conditions reflecting those encountered in the surveyed plantations were used to evaluate the sampling methods. Table 2 contains parameters for the simulated populations. Each rootstock density was paired with each pattern type within each stand age. Thus, a total of 24 simulated populations were produced, each of them 16 acres in size.

Random sampling was simulated for all methods examined. Sample size ranged from 16 to 80 sample units, depending upon sampling intensity. A sample mean and sample variance were calculated for each sample. A running mean of means was calculated to determine when and if the sample mean stabilized. If the mean of means did not differ by more than 0.5 percent from any of the 10 previous means of means, sampling ceased. Each simulated population was sampled a maximum of 200 times.

To compare the 42 sampling rules, we used four evaluation criteria: relative bias, relative precision, sample variance, and between-sample variance. Relative bias was expressed as the absolute difference between the ratio of sample mean to population mean and 1. Relative precision was the percentage of sample means falling within 5 percent of the population mean. Sample variance was expressed as the mean of the sample standard errors. Variance between samples was calculated as the variance of the sample means about the mean of sample means. Both variance terms were divided by the population mean to remove the effect of different population densities.

To select the most promising sample method, the best sample rule (based on minimum sample variance) for each method was selected for each simulated population. The eight sample methods were then ranked (from 1 to 7, best to worst) within each simulated population. The mean rank of each sampling method was then calculated for each of the four pattern types.

Results

In general, all point and plot methods yielded relatively unbiased sample means (within 1 to 3 percent of the true means). Batcheler's (Warren and Batcheler 1979) triple-point distance estimator was affected by spatial pattern. The method underestimated density in uniform stands, and overestimated density in clumped stands. The data in table 3 show the mean ranking of each method by spatial pattern type for all evaluation criteria. The ranking closest to 1 indicates the best rule for each criterion.

Table 1. Summary of sample methods evaluated

Sampling method	Type[1]	Sample rule	Sampling intensity in points per acre
Circular plot	FP	0.002, 0.004, 0.01 acre	(1% sample)
Square plot	FP	0.002, 0.004, 0.01 acre	(1% sample)
Rectangular plot	FP	0.002, 0.004, 0.01 acre	(1% sample)
Horizontal point	VP	100, 200 CAF[2]	1, 2.5, 5
Horizontal line	VP	100, 200 CAF	1, 2.5, 5
Vertical point	VP	30, 45, 60 degrees[3]	1, 2.5, 5
Vertical line	VP	30, 45, 60 degrees	1, 2.5, 5
Triple-point distance	VP		1, 2.5, 5

[1] FP = fixed area plot, VP = variable area plot.

[2] CAF = Crown area factor (square feet per acre).

[3] Vertical angle.

Table 2. Summary of parameters of 24 simulated hardwood rootstock populations (each stand age was combined with each rootstock density-pattern type combination)

Stand age	Total height	Crown area	Rootstock density	Pattern type
yr	*ft*	*sq ft*	*per acre*	
3	4.9	4.0	500, 1,500	uniform, random, light
6	6.9	7.2	2,500	clumping, heavy clumping

Factors that increased the probability of selecting a rootstock also increased relative precision for all variable- and fixed-plot estimators. Pattern affected relative precision: estimators exhibited the greatest relative precision in uniform stands and the lowest relative precision in strongly clumped stands. In this study, variable plot estimators exhibited the highest relative precision (table 3).

Spatial pattern affected the variance measures of all estimators. Variance was lowest in uniform stands and greatest in clumped stands. This agrees with the findings of others (e.g., Oderwald 1981). In our study, variable plot methods exhibited smaller variances than fixed plot estimators. Of the variable plot methods, horizontal line sampling exhibited the smallest variances (table 3).

Summary of sampling study

In this study, variable-plot methods generally outperformed fixed-plot methods. As the data in table 3 illustrate, horizontal line sampling ranked highest of all methods examined. Based on these results, horizontal line sampling appears to be a promising method to field test. It is unbiased, and has high precision and low variance.

Horizontal point sampling has been used with success in shrub communities, and was generally the most time-efficient method (Cooper 1963). Cooper found that prism angle gauges were unsatisfactory, since individual crowns could not be distinguished when crown cover exceeded 35 percent. This may prove to be the case with horizontal line sampling. Sampling tubes or other types of angle gauges might be more effective.

Summary and conclusions

A computer program has been developed that successfully simulates the hardwood rootstock component of young loblolly pine plantations. The spatial pattern of the rootstocks is controlled by inputting a desired value of a commonly used pattern index, Pielou's α. Methodology has been developed whereby point pattern can be controlled with some degree of precision and in a time-efficient manner. This permits further examination of commonly used pattern indices and their relationship to underlying point patterns. Work to simulate spatial pattern as a function of other indices might be accomplished more easily.

The sampling study showed that both fixed and variable plot estimators were unbiased at low sample intensities. Pattern affected precision and variance of all estimators. Of all sampling methods examined, horizontal line sampling is recommended for field testing to determine its applicability and ease of use.

Table 3. Mean ranking of sampling methods by spatial pattern and evaluation criteria

Spatial pattern	Sampling method	Relative bias[1]	Relative precision[2]	Sample variance[3]	Between-sample variance
Uniform	Circular plot	3.50	4.17	4.83	3.00
(a = 0.6)	Rectangular plot	5.50	4.75	5.17	4.83
	Horizontal point	2.83	2.67	3.00	4.00
	Horizontal line	2.83	2.42	1.00	1.50
	Vertical point	2.75	4.75	5.00	5.17
	Vertical line	3.17	2.42	2.00	2.50
	Triple point	6.58	6.83	7.00	7.00
Random	Circular plot	3.83	5.33	5.33	3.67
(a=1.0)	Rectangular plot	5.08	5.75	5.67	5.33
	Horizontal point	3.58	2.08	2.50	2.17
	Horizontal line	3.00	1.75	1.00	1.17
	Vertical point	4.42	3.75	4.00	4.92
	Vertical line	3.00	2.42	2.50	3.75
	Triple point	5.08	6.92	7.00	7.00
Light clumping	Circular plot	4.25	5.58	5.00	4.33
(a=1.6)	Rectangular plot	5.50	5.50	6.00	5.33
	Horizontal point	2.17	1.75	2.17	1.33
	Horizontal line	3.17	1.58	1.00	1.67
	Vertical point	3.50	4.08	4.00	5.00
	Vertical line	2.42	2.67	2.83	3.50
	Triple point	7.00	6.83	7.00	6.83
Heavy clumping	Circular plot	4.50	5.50	5.00	5.17
(a=2.2)	Rectangular plot	5.17	5.83	6.00	6.00
	Horizontal point	2.42	2.42	2.00	2.17
	Horizontal line	3.42	1.33	1.00	1.33
	Vertical point	2.75	4.17	4.00	4.50
	Vertical line	3.08	2.25	3.00	2.67
	Triple point	6.67	6.50	7.00	6.17

[1] Relative bias = $\left| \frac{\text{sample mean}}{\text{true mean}} - 1.0 \right|$

[2] Relative precision is the percentage of sample means within 5 percent of the true mean.

[3] Variance of sample means about the mean of sample means.

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