OPERATIONAL TEST OF 3-P SAMPLING FOR SEEDLING INVENTORY AT THE CAROLINA NURSERY

J. P. Conn and E. E. Watson

Abstract.--Three-P techniques may be used to create a nursery seedbed inventory system having greater reliability than a conventional seedling inventory without increasing measurement time or inventory cost per unit of seedbed area. Additionally, the calculations used to verify the statistical accuracy of a 3-P inventory are straightforward and cull standards may be easily incorporated. An inventory labor cost savings of at least $1,000 per year has been realized at the Carolina Nursery by using a 3-P seedling inventory system.

INTRODUCTION

Conventional nursery seedling inventory can be a time consuming, inaccurate and expensive process. Sampling methodology and intensity vary from one nursery to another, but generally involve taking fixed area plots located in some random or systematic manner. Although most nursery managers realize the importance of an accurate seedling inventory, available labor, time and cost often limit sampling intensity. This paper presents a sampling system which can achieve acceptable levels of reliability without an inordinate commitment of time and money.

This paper is not intended to teach 3-P sampling theory. Some basic reader knowledge of 3-P sampling principles is assumed.

OBJECTIVES

Development and testing of a new system for seedling inventory at Champion's Carolina Nursery (annual seedling production capacity of 25 million seedlings) to achieve the following objectives:

--Increase reliability of seedling count estimates without increasing measurement time or cost per unit of seedbed area.

--Provide an easy method for verification of statistical accuracy.

--Define a cull seedling at inventory time in the late summer.

These objectives can be accomplished by ocularly estimating the number of seedlings in systematically located fixed area plots and using 3-P sampling techniques (Grosenbaugh 1965) to select subsamples for more precise counting.

3-P SAMPLING

Grosenbaugh (1963) developed probability proportional to prediction sampling, or 3-P sampling, to improve sampling efficiency. This system is an accurate and efficient method of sample selection, but it is sometimes considered difficult to master. This is unfortunate because the concept is actually straightforward and often results in significant inventory cost reductions. In practice, 3-P sampling is usually associated with timber inventory using dendrometers to measure stem diameters and computer programs to process large volumes of data. Actually, 3-P sampling is independent of both dendrometry and computer processing and has many possible applications for both timber and non-timber inventories (Johnson 1972).

Three-P sampling enables nursery managers to increase inventory confidence while avoiding cost increases associated with conventional sampling methods. The cost of taking the required number of samples to maintain a desired confidence level often becomes prohibitive when using conventional methods of counting each seedling in systematically or randomly established fixed area plots. As a result, accuracy is often sacrificed by reducing sample size to a workable level. Three-P sampling provides an efficient, accurate and cost effective seedling inventory where high confidence levels are maintained, even though inventory results are based on actual counts of only a small percentage of the entire population. The three basic steps of the 3-P nursery inventory system are:

--1. Ocularly estimating number of seedlings in fixed area sample plots.

--2. Selecting a few ocularly estimated plots for exact counting based on probability proportional to predicted seedling count.

--3. Carefully counting plantable seedlings in each plot selected in step 2.

In 3-P sampling, as well as random sampling, the coefficient of variation (C) is directly related to the required number of samples by the following formula:

$$n = \frac{C^2 \ t^2}{e^2} \qquad (1)$$

where

n = required sample size,
C = coefficient of variation,
t = t-value obtained from a table of Student's t distribution (for a given confidence level and degrees of freedom), and
e = allowable error expressed as a percent (after Dilworth and Bell 1975).

The difference in definition of C distinguishes 3-P sampling trom conventional random sampling. Normally, C refers to the dispersion of individuals around the mean; however, in 3-P sampling, C is the dispersion of the ratios of measured values to estimated values around the average of these ratios. Thus, 3-P sampling provides an opportunity to lower C by making ocular estimates as accurately as possible, and thereby reducing the number of samples required.

METHODS AND MATERIALS

Inventory preparation.--Before starting the inventory, the following should be determined:

--1. Minimum seedling morphology in September which assures development into a "plantable" seedling by lifting time (early December). For the Carolina Nursery, loblolly pine seedlings greater than 4 inches tall and possessing woody stem tissue in early September are considered to be future plantables. Specifications for "plantable" seedlings at lifting time include a height of 8 to 10 inches, a minimum 3/16 inch root collar diameter and the presence of a woody stem and secondary needles.

--2. Estimates of the mean and standard deviation of both the ocularly estimated plot counts and the actual count to estimated count ratios. These parameters may be determined by ocularly estimating then accurately counting plantable seedlings, using a 1 x 4 ft sampling frame, in approximately 60 plots randomly located in the area to be inventoried. Parameter estimates may also be obtained from history plots maintained in the nursery beds.

Based on these preliminary assessments, the required number of plots for estimated and/or actual seedling counts in each inventory unit (nursery section) is calculated for several levels of confidence and allowable error (Equation 1). Depending on uniformity of seedbed density and precision of estimated counts, confidence levels and allowable error percentages are selected which provide statistically acceptable results while maintaining a reasonable number of samples per nursery section. Using the 1982 Carolina Nursery crop as an example, estimates within 3% of the true mean at the 90% confidence level could be obtained by taking approximately 82 estimated and nine actual plot counts in a nursery section of 4,500 bed-feet. These standards were adopted for the 1982 seedling inventory.

In each nursery section, plots to be carefully counted are selected with the aid of random number tables. These tables are generated using the previously determined numbers of plots to be estimated and counted exactly in each section, average seedbed density and maximum predicted number of plantable seedlings to be found in any 1 x 4 ft sample plot (after Dilworth and Bell 1975).

Computerized tally sheets with appropriate random number lists are then printed for each nursery section. Inter-plot distance for each nursery section is determined by dividing the total bed length by the required number of plots to be estimated. To begin the inventory in a section, a random distance between 1 ft and the inter-plot distance is selected. This distance is then measured down the first bed in the section to randomly locate the starting sample plot. Subsequent sample plots are located by measuring the inter-plot distance down the seedbed from the previous plot. Measurement of intervals between plots continues from the end of one bed to the start of the adjacent bed. This results in all beds in a section being sampled in a serpentine pattern.

Void areas, defined as portions of nursery bed 2 ft or more in length which contain no plantable seedlings, are not included in the inventory. Areas lacking plantable seedlings due to seeder skips, herbicide damage, heavy weed infestation, or small seedling size are considered void. Void areas are omitted when measuring inter-plot distance; however, the length of each void area in a section is measured and recorded on the tally sheet in order to exclude the total non-productive area from the inventory of that section.

Data collection.--Inventory crews consist of two people. After locating a sample plot, the crew positions the edge of the 1 x 4 ft sample frame in the seedbed, taking care not to damage any seedlings. Each crew member estimates by rapid mental count (i.e., without physically separating the seedlings) the number of plantable seedlings in his half of the sample frame. Each crew member's estimate and the total of the two estimates are then recorded. Next, the estimated plot total is compared to the random number associated with that plot. If the estimated plot total is greater than or equal to the random number, a careful count of plantable seedlings is taken and recorded; otherwise the crew moves on to the next sample plot. Sampling continues until all beds in the section have been inventoried. Top pruning seedlings to a uniform height a week or two prior to starting the inventory aids in the estimation process.

Calculations.--After completing the sampling in each section, total length of void seedbed is subtracted from total bed length in the section to compute net length of seedbed containing plantable seedlings (L). A ratio of actual count to estimated count is calculated for each plot where an actual count was taken. The sum and standard deviation of the ocular estimates and the actual-to-estimated count ratios are calculated for each inventory unit using standard statistical procedures (Steel and Torrie 1980). The predicted number of plantable seedlings contained in a given nursery section is then computed using the following formula:

$$T = \frac{T_O \times T_R \times L}{n_o \times n_a} \qquad (2)$$

where

T = predicted total number of plantable seedlings in a given nursery section,

T_O = total of the ocular estimates,

T_R = total of actual-to-estimated count ratios,

L = net length of seedbed in the section containing plantable seedlings,

n_O = number of ocularly estimated plots, and

n_a = number of plots actually counted.

Verification of sample intensity.--To determine if the sampling intensity used in a section is sufficient to remain within allowable error limits at the desired confidence level, coefficients of variation are calculated both for ocular estimates of bed density and ratios of acutal-to-ocularly estimated plot counts. The coefficient of variation of the ocular estimates (C_o) is calculated using the following formula:

$$C_o = \frac{s_o \times n_o}{T_o} (100) \tag{3}$$

where

C_o = coeffcient of variation of ocularly estimated plots,
s_o = standard of deviation of estimated counts,
n_o = number of ocularly estimated plots, and
T_o = total of the ocular estimates (after Freese 1967).

The coefficient of variation of actual-to-estimated count ratios (C_R) is calculated using the following formula:

$$C_R = \frac{s_R \times n_a}{T_R} (100) \tag{4}$$

where

C_R = coefficient of variation of actual-to-estimated count ratios,
s_R = standard deviation of actual-to-estimated count ratios,
n_a = number of actual plot counts taken, and
T_R = total of actual-to-estimated count ratios (after Freese 1967).

After calculating values of C_o and C_R, the following formula is used to determine if a sufficient number of plots have been estimated in a section t satisfy the desired level of accuracy:

$$n_o = \frac{C_o^2 \quad t^2}{e^2} \tag{5}$$

where

n_o = number of ocularly estimated plots needed,
C_o = coefficient of variation of ocular estimates (Equation 3),
t = t-value obtained from a table of Student's t distribution (for a given confidence level and degrees of freedom), and
e = allowable error percentage (after Dilworth and Bell 1975).

Similarly, a check to determine if a sufficient number of actual counts have been made is conducted using the following formula:

$$n_a = \frac{C_R^2 \; t^2}{e^2} \qquad (6)$$

where

n_a = number of actual plot counts needed,

C_R = coefficient of variation of the ratios of actual-to-estimated plot counts (Equation 4),

t = t-value obtained from Student's t distribution, and

e = allowable error percentage (after Dilworth and Bell 1975).

Once the required number of estimates and actual counts have been determined, a comparison with actual sampling levels is made and additional plots are taken as needed until desired levels of accuracy are achieved.

3-P NURSERY SAMPLING IN PRACTICE

Following a brief training session, sampling began with little difficulty. All personnel involved were required to spend approximately 30 minutes the first day of inventory and about 5 minutes on each succeeding day verifying estimation techniques prior to actual sampling. By the second day of inventory the procedures of 3-P sampling had become routine and a 0.7 acre nursery section could be completed in 1.5 to 2 hours. As a result, all loblolly pine seedlings in the nursery (about 17 million) were inventoried using either two or three crews working four to five hours per day for nine days. Approximately 100 man-hours were needed to sample the entire seedling crop.

As the inventory progressed, estimates became increasingly accurate, with coefficients of variation in the ratios of actual-to-estimated counts (CR) almost always less than 5%. In many cases, the value of C was less than 2%. Subsequent information from the 1982-83 seedling harvest slows that inventory figures were quite accurate, with numbers of plantable seedlings lifted agreeing closely with the number predicted. For example, 7,327 bags of Western Carolina piedmont and 4,065 bags of Eastern Carolina coastal loblolly pine seedlings were lifted from the Carolina Nursery during the 1982-83 lifting season. The 3-P inventory predicted that 7,589,000 and 4,272,000 plantable seedlings, respectively, would be lifted from each of these two seed sources. This would give an average of 1,037 plantable Western Carolina piedmont seedlings per bag and an average of 1,051 plantable Eastern Carolina coastal plain loblolly pine seedlings per bag. These averages were in fact verified by spot bag counts made at various times during the lifting season. When the 60 preliminary samples were taken prior to operational inventory, the number of seedlings in the plots predicted by 3-P techniques was only 1.2% different from the number obtained by actually counting each plantable seedling in every plot.

The fact that the number of seedlings lifted agreed closely with predicted counts also demonstrates the suitability of the culling standards used. Seedlings predicted to attain plantable size had in fact grown sufficiently by lifting time to be considered plantable. Culling standards must be developed for each nursery and species, based on time of year the inventory is taken and historic growth patterns.

SUMMARY

One of the main benefits of using 3-P sampling for nursery inventory is that accuracy can increase substantially without increasing the time required to do an even less accurate inventory by conventional sampling methods. Conservatively, in the case of Champion's Carolina Nursery, inventory costs would have doubled if conventional inventory methods had been used to obtain an estimate as accurate as that of the 3-P system. During the 1982-83 lifting season a labor cost savings of over $1,100 was realized by using 3-P sampling to inventory seedlings and inventory accuracy was improved. Labor cost savings will vary from nursery to nursery, but as size or capacity of a nursery increases, so will cost savings.

Overall, the 3-P method of nursery inventory works quite well and its use is recommended. The system permits an increase in sampling intensity and inventory accuracy without increasing sampling time spent per unit of seedbed area. Three-P sampling also provides an easy means of checking to see if the number of samples taken in a given sampling unit is sufficient to achieve desired accuracy levels. Additionally, cull standards are easily incorporated into the system to aid in determining which seedlings will not be plantable by lifting time. Current plans are to use 3-P nursery sampling for all future inventories at the Carolina Nursery with computer analysis included to increase data processing efficiency.

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