A LOGGING RESIDUE SAMPLING METHODOLOGY FOR NORTHEASTERN ONTARIO

by

Xilin Fang ©

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ABSTRACT

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Key Words: logging residue, plot sampling, line and circular transect sampling, stratification, poststratification, butts only, partial logs.

The objective of this study was to develop and test statistically justifiable methods of estimating logging residue in cutover areas of northeastern Ontario. Two sampling designs and ten sample units were chosen and tested using computer simulation in both finite and infinite sample frames for six cutovers with merchantable residue. All six populations showed clustered spatial distributions. Degrees of clumping were strongly related to residue density rather than cutover type. Precision of estimating residue volume was poorer than that of estimating residue density. Measuring butts only on plots or narrow strips resulted in poor estimation of residue density because of void sample units. Measuring partial logs or using transects achieved higher precision of estimation. A circular transect design was developed for avoiding biased estimation caused by residue orientation. The use of circular transects resulted in better estimates than double or triangular transects. Systematic sampling using randomly oriented transects is unbiased but gave no advantage over simple random sampling. Random sampling with poststratification using circular transects and simple random sampling measuring partial logs on narrow strips are two alternatives to single line transect methods. However, none of the above methods could provide precise estimates of residue pieces per hectare for cutovers with low densities of residue. The reliable minimum estimate method could apply to residue inspection in certain low density cutovers, but no satisfactory results for cases with very low density of residue (less than 17 piecesper hectare) occurred. Alternate methods of assessing stumpage aimed at eliminating the problem of residue should be investigated.

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CHAPTER ONE: INTRODUCTION

THE PROBLEM

The expansion of the world population is increasing the pressure on forests for wood-derived products and forest land for agriculture and other uses. Fibre shortages in certain markets and fire hazards on cutovers demand better utilization of forest products.

The concept of the merchantable stem has changed over the decades (Hakkila,1989). Yesterday's residue has often become today's raw material. Traditional forest inventory often recognizes only that part of a tree which is useful to forest industries (Hakkila,1989). Therefore, to meet the changing concept of forest residue, inventory methods have to be updated.

Logging residue consists of unmerchantable tops of stems, branches, undersized trees, culls, broken stem parts and stumps (Hakkila 1989), and missed merchantable logs. Although most residue can be utilized for forest products, specific fields of forestry are often only interested in particular kinds of residue. For example, a fire manager only wants to know how many small combustible pieces of wood are left on the ground. Since logging residue can range widely depending the quantity of biomass, size and pattern of distribution, there should be individual sampling designs applicable to the type of information required.

To determine the degree of utilization on cutovers, the Ontario Ministry of Natural Resources (OMNR) has been conducting surveys to determine if scaling of residue on individual cutovers should be performed and if penalties should be levied under Section 26 (Wasteful Practices) of the Crown Timber Act (Government of Ontario 1985). Since cutover surveys are done at the district level, some problems have been encountered on a regional basis with companies who complain that different districts apply different utilization standards (Anonymous 1991). To alleviate this concern, the OMNR has determined that the precision of the survey method should be standardized throughout the Northeastern Region. The main purpose of a utilization survey, for the OMNR, is to determine the number of pieces or volume of merchantable logs left on the cutovers after harvest.

The main methods used in the past for logging residue surveys include fixed area plots, line intersect sampling and large scale photography (Anonymous 1991).

A fixed area plot survey is a traditional method for forest inventory. It is simple to set up, but does not deal easily with logs crossing plot boundaries. The use of fixed area plots for residue surveys has proven costly and of dubious accuracy (Warren and Olsen 1964).

The use of large-scale photography for residue surveys requires less field work, but needs a large capital investment for equipment and skilled people to carry out the work (Dendron Resource Surveys Ltd. 1981).

The line intersect method is up to 70 percent faster than plot methods (Bailey 1970) because of the narrow width of the plot which leads to reductions in search time (Warren and Olsen 1964). This method is suitable for cutovers with many small pieces of residues. But, for a cutover with an uneven distribution of residue, the method still requires extensive field work to achieve high levels of precision (Pickford and Hazard 1978).

Since the pieces of merchantable logs left on the ground are mostly due to logger's mistakes, such as timber on the edge of designated cut areas or left isolated at the end of a day's work when the logger starts a new area the next day (Brown 1979), the patterns of the residue distribution vary both from cutover to cutover and within individual cutovers. Low densities of residue will increase the variation among sample plots resulting in low precision of estimation for both residue density and volume. Therefore, none of the above three methods seems to be suitable for merchantable logging residue surveys.

In 1991, the OMNR applied a "butts only" scale strip plot method to survey harvesting residue. With this method only those logs whose butt end are located in the strip are measured. The butts only method overcomes the problem of dealing with logs which cross plot boundaries. Using a long narrow strip plot can save search time. Lacking in this design were an estimator for precision and expected survey costs.

OBJECTIVES OF THE STUDY

The objectives of this study are to review the technology for conducting logging residue surveys at the small clearcut level, to evaluate the relevancy of specific methodologies to estimate logging residue classed as infractions of the Crown Timber Act, and to develop and test a statistically justifiable method of estimating logging residue in cutover areas of northeastern Ontario. Any method found to be acceptable statistically should also be practical in application and cost effective.

To fulfil the above objectives, this project compared different residue sampling methods in various cutovers. This may be done through repeated field sampling, using computer simulation on artificial populations or using computer simulations on representative real populations (Murchison 1984). Since field trials are very expensive and time consuming, this study used computer simulation methods. In order to produce results reflective of conditions to be found in northeastern Ontario, the use of real populations was desirable. This required data for a set of small, real cutover populations. Therefore, to meet the objectives of the study, the following work was done:

(i) Obtaining a set of coordinate data of logging residue on various types of cutover sites in northeastern Ontario.

(ii) Describing the OMNR butts only method which may be applicable in northeastern Ontario.

(iii) Identifying and testing different sampling techniques which may provide improved precision of estimation through computer simulation.

(iv) Discussing the sampling precision for each method to identify efficient and suitable methods for application in the OMNR Northeastern Region.

CHAPTER TWO: LITERATURE REVIEW

SAMPLING TECHNIQUES

Cochran (1977) pointed out that for any but very small populations, sampling speeds data collection, reduces survey costs, and ensures reliable accuracy compared with complete enumeration. The purpose of sampling theory is to make sampling more efficient and to develop methods of sample selection and estimation that provide, at the lowest possible cost, estimates that are precise enough for any specific purpose.

Population and Sample Frame

The objective of surveying is to examine natural populations, but sample designs are usually carried out in sample frames consisting of arbitrary rather than natural sample units (SUs). Pielou (1977,1979) distinguished between natural and arbitrary SUs. Natural SUs are elements that occur in discrete segments of habitats while arbitrary SUs can be points, lines and various shaped plots which are parts of large, continuous habitats, such as trees in a forest (Ludwig and Reynolds 1988).

A population can be defined as a set of individual characteristics of a universe or an aggregate from which the sample is chosen (Cochran 1977, Jessen 1978). The individuals of a population are of the same kind and differ from each other in respect to typical features or attribute values (Loetsch *et al.* 1973). A sample frame is a set of sample units, used for performing the sampling operation (Jessen 1978). When population units are chosen as sample units, the sample frame and the population are identical. However, in many practical situations, a given universe may conceivably contain a number of alternate sample frames.

The sample frame could be either finite for non-overlapping sample units, such as strips and square plots, or infinite for overlapping sample units, such as points or transects. The choice of sample frame is an important aspect of any sampling design (Jessen 1978).

With residue sampling, population units are individual pieces of residue, while sample units are usually arbitrary units: fixed area plots or line transects. The size of arbitrary SUs is very important when sampled populations with clustered spatial distributions. In populations showing clustered distributions, larger units tend to give about the same number of individuals per sample unit leading to consistent estimation which provides increased precision (Ludwig and Reynolds 1988).

Spatial Pattern of Population Characteristics

In order to design a good sample frame, it is necessary to know the spatial pattern shown by a population. Ludwig and Reynolds (1988) summarized others' work and pointed out that there are three types of spatial patterns for individuals of a population: random, clumped and uniform. They also presented three spatial pattern analysis (SPA) model types which could be used for detecting the spatial patterns: distribution models, quadrant variance models and distance models.

Frequency distribution models are suitable for identifying distribution patterns, such as log orientation. Pielou (1977) suggested that the Poisson distribution is recommended as a model to identify random dispersions and the negative binomial for clumped dispersions. When the sample size is less than 30 sample units, Ludwig and Reynolds (1988) recommended the index of dispersion (calculated as the ratio of the variance to the mean) as a test for the agreement of the data with a Poisson series. In addition, many indices have been proposed to measure the degree of clumping in a population, but Green's index appears to be the best because it is independent of the total number of individuals in the sample (Ludwig and Reynolds 1988).

Since logging residue spatial patterns are determined by both location and orientation, different analysis methods may be required to identify each individual logging residue piece. Quadrat variance models are suitable for identifying the spatial distribution shown by a population. The model detects spatial patterns by examining the effects of varying the size of arbitrary sample units applied to a population. Ludwig and Reynolds (1988) suggested that both two-term-local-quadrat-variance and paired-quadrat-variance methods were good for detecting clumped patterns.

The distant model can be used to avoid the problem of arbitrary sample units affecting spatial pattern and provides a fast and easy survey method for pattern identification (Ludwig and Reynolds 1988). Ludwig and Reynolds (1988) recommend a "T-square" index of spatial pattern as a powerful index of pattern recognition using the distance model.

Sampling Designs

To improve sampling efficiency, one often uses combinations of multi-level and unequal probability sampling methods: for example, sampling with probability proportional to the size of sample elements (PPS) (Cochran 1977). There are two special cases of two-stage sampling: stratified and cluster sampling. When the variance of the first stage is greater than that of the second stage, stratified sampling is efficient, otherwise, cluster sampling is more efficient (Fu and Chen 1979).

In residue sampling, no matter which sampling method is used, the cluster sample rule should be used if the sample unit covers more than one population unit or residue piece.

Jessen (1978) summarized that the choice of selection of sample units within clusters is influenced in two ways: (1) efficiency of estimation can be increased by putting unlike elements together while costs are usually decreased by putting geographically contiguous elements together; and (2) when costs are ignored, the smaller the size of sample unit, the more efficient the unit. But when costs and other practical matters are considered, the optimum size of a sample cluster usually becomes larger.

Systematic sampling is another way to improve sampling efficiency. Since systematic samples are spread evenly over a population, they are convenient to draw and to execute (Cochran 1977). However, the precision of a systematic sample is greatly dependent on the properties of population to be sampled. This method may give biased estimates in populations with periodic variation (Cochran 1977).

COMPARISON OF SAMPLING DESIGN

Murchison (1984) summarized characteristics of a good sample design as having: (1) a clear statement of inventory objectives with specification of the precision desired; (2) specification of the population, sample frame and method of drawing sample units; (3) methods for measuring variables of interest; (4) provision of estimators for calculating desired estimates based on the sample; (5) high precision; (6) unbiasedness, having small bias, or predictable bias; (7) simplicity of application; and (8) cost effectiveness.

To evaluate alternate or new sampling methods, we have to apply each method to the same population, analyze the results and compare the different methods on the basis of their costs and precision achieved. For example, Oderwald (1981) compared the precision of point and plot sampling for basal area estimation. Yandle and Wiant (1981) compared sampling efficiencies of fixed radius circular plots with overlap versus without overlap by evaluating variances of estimation of the population total.

As stated earlier, there are three ways to test sample designs and sampling methods: (1) field trials, (2) computer simulation using small real populations, and (3) computer simulation using artificial populations (Murchison 1984). In practice, comparison using field trials is often highly undesirable because experimentation in real populations is unrepeatable due to costs and time limitations (Neelamkavil 1987). The use of artificial populations is usually limited by our knowledge of real population characteristics, and therefore the simulation results may be not applicable in real populations. Any real, small population is a part of a realistic larger population and may be suitable for representing the larger population (Murchison 1984). The use of computer simulation in a real population is exactly the same as running field trials which could be conducted by repeatedly sampling the same real population. Computer simulations are far more cost effective than conducting field trials. Therefore, considering cost and limited time, computer simulation using small real populations is recommended for testing sampling designs (Murchison 1984).

COMPUTER SIMULATION

Neelamkavil (1987) pointed out that the purpose of computer simulation and modelling is to aid in the analysis, understanding, design, operation, prediction or control of systems, without actually constructing and operating the real thing. A simulation can be a controlled statistical sampling technique that is used to obtain approximate answers. Thus, simulation methods are very useful when analytical and numerical techniques are unable to supply exact answers for some problems (Lewis and Orav 1989).

Neelamkavil (1987) further described that simulation is similar to laboratory experiments conducted by scientists to gain insight into existing theories or to develop and validate new theories. It has some limitations such as data collection, expense of computer use and validation of results. Analysis and interpretation of results from simulation requires good knowledge of probability and statistics. Some situations simulated may not be demonstrated to be useful until they are implemented in practice (Brateley *et al.* 1983)

A popular simulation method used in forestry is called Monte Carlo simulation. Monte Carlo simulation is performed by using an approximate stochastic simulation model of a deterministic system (Neelamkavil 1987). It uses repeated trials of randomly selected samples from data according to specific selection rules (Murchison 1984).

EVALUATION OF RESULTS

Two criteria, accuracy and precision, are often used to evaluate sampling results (Husch *et al.* 1982). Accuracy refers to the deviation of a sample estimate from the corresponding parametric value while precision refers to the deviation of the sample estimates from their own mean (Cochran 1977, Husch *et al.* 1982). Precision of a sample does not always correspond to its accuracy. The lack of accuracy of estimation is called bias. It is possible to obtain a precise, but biased estimate due to systematic errors (Husch *et al.* 1982). Therefore, when a population mean is known, the accuracy should be considered first for evaluating sampling results.

To compare sampling results from different populations, which may have different mean values, we have to use relative accuracy or relative precision. Usually, allowable error or relative error represents relative accuracy, while coefficient of variation of a sample mean or relative standard error represents relative precision (Cochran 1977, Husch *et al.* 1982, Jessen 1978). When the confidence level to be calculated, an estimate of the relative precision is multiplied by student's "t" (Loetsch and Haller 1973).

In forest inventory, sampling estimates are usually expressed as a range or confidence interval (Husch *et al.* 1982). For timber surveys, the lower limit of the confidence interval is often suggested as a reliable conservative estimate of the stand parameter of interest, usually volume (Husch *et al.* 1982). This lower bound is expected to underestimate the parameter. Dawkins (1957) called this statistic the reliable minimum estimate (RME). Since the confidence interval is dependent upon sample size, the reliability of the RME method is limited by the sample size.

SAMPLING METHODS APPLIED IN LOGGING RESIDUE SURVEYS

Fixed Area Plot

Fixed area plot sampling methods are conventional surveying methods which have been shown to be effective for measuring small fuels (Brown 1971) and best for areas where the residue is small in size, evenly distributed and not very abundant (Hakkila 1989).

The residual volume on the site and the type of harvesting system used have a significant effect on the amount of time a plot method takes (Martin 1976). Therefore, plot sampling is more manpower intensive than line intersect methods (Bailey 1970). Using fixed area plots also leads to difficulty in dealing with logs which cross plot boundaries (Warren and Olsen 1964). Guidelines must be set for the inclusion or exclusion of pieces that cross boundaries (Martin 1976). Runesson and Kloss (1982) tried a method that excluded pieces on the left boundary and tallied pieces on the right boundary to improve plot sampling. If a piece crossed both plot-half boundaries, only the length laying inside the plot boundary was measured. The OMNR (Anonymous 1991) used "butts only" scale plot method to overcome the disadvantages of logs crossing boundaries in conventional plots, and this method loses little accuracy when compared to complete enumeration.

Since plots are arbitrary sample units, their size and shape should determine the sample frame. When the population is very clumped, larger sample units are desirable in order to maintain approximately equal values for all sample units. This may lead to better precision of estimation. But Warren and Olsen (1964) pointed out that there is no worthwhile advantage for altering the size and shape of the plots except that long rectangular plots seemed to sample the pattern of distribution for logging residue more adequately and, if narrow in width, reduced the searching time.

Large-scale Photography Method

Large-scale Photography (LSP) method is an approach combining information directly measured from large scale aerial photographs (scale of 1:1500 to 1:15000) with data collected from a limited amount of field sampling for people to assess forest characteristics (Macleod 1981). According to Dendron Resource Surveys Ltd. (1981, 1984), the use of large-scale photography for residue sampling requires less field work and provides results as accurate, or more accurate than line intersect and plot methods do. It is suitable for surveys in remote and inaccessible areas. The disadvantages of this method are that it requires a large capital investment for equipment and aircraft, and the use of photography also requires highly skilled people.

The Line Intersect Sampling

Theoretical Developments

Warren and Olsen (1964) first developed a line intersect residue sampling method according to the idea that long, narrow, rectangular plots were more time efficient than square or circular plots. The method produced good precision at much lower cost than conventional plot methods but required a preliminary test for randomness in the orientation of the residue pieces.

Van Wagner (1968) recognized the advantages of increased accuracy and relative simplicity of estimating piece volume from intersected cross-sectional areas and gave considerable improvements in the theoretical background of line intersect sampling. He also computed the maximum bias due to log orientation relative to three different sampling line systems: one line, two lines at right angles and three lines oriented at 60 degrees to each other.

Brown (1970,1971) extended Van Wagner's development for cylinders into a planar intersect method for populations containing both cylinders (twigs, branches) and parallelepipeds (flat leaves, bark flakes).

Howard and Ward (1972) examined three patterns of sampling (i.e., unidirectional, L-shaped and random) and found that the random orientation sample line was best for areas where topography and logging create residue orientation patterns. The unidirectional pattern of sampling was the fastest way for sampling areas with random orientation of residue. They also gave a table of sampling intensity required to meet various levels of precision.

Brown and Roussopoulos (1974) further developed the line intersect method to correct biases caused by non-horizontal particle angles when estimating volumes of small fuels. Their methods are suited to sampling fuel volumes and surface areas.

De Vries (1974) proved that Van Wagner's formula could be derived by treating the method as a form of Buffon's needle problem (Pickford and Hazard 1978). Meanwhile, he gave multi-stage sampling designs for the line intersect method.

Van Wagner (1976) proved that the line intersect result based on intersection diameters was the best estimate of wood volume on the ground and the fastest possible way to obtain the estimate. The use of measuring intersection diameter also further simplifies the procedure of the line intersect method.

Meeuwig *et al.* (1978) applied the line intersect method to estimate the volume of crown-wood and standing trees, by counting crown projections which intersected the line transect. This can be treated as an extension of Buffon's needle problem (Uspensky 1937).

De Vries (1979, 1986) further developed the mathematical basis for line intersect sampling and pointed out that it is a form of PPS sampling. He even extended the method into general theory and used the method to estimate vegetation and density of mobile animal populations. But he did not do any practical applications.

Practical Applications

Along with the theoretical developments of the line intersect method, many practical applications have been demonstrated since the method was developed.

Bailey (1970) tested the line intersect method in the field in British Columbia. He concluded that reliable estimates of logging slash could be made up to 70 percent faster using the line intersect method when compared to plot methods.

Martin (1976) found that the line intersect method only took one-fifth to one-third the time of the plot method, and the accuracy was not significantly affected by species composition, harvesting prescription, degree of slope, presence or absence of roads or the length of the residual pieces.

Meeuwig and Budy (1981) applied a combination design of point sampling and line intersect methods. They found that point sampling is generally more efficient than line intersect methods. They recommended that point sampling should be used whenever practical. However, for situations with irregular stem species and poor viewing within the stand, line intersect methods had to be used.

Howard (1981), Howard and Fiedler (1984) and Howard and Setzer (1989) used line intersect sampling to estimate scattered logging residue and used a separate procedure

(Little 1982) to estimate large piles of slash volume. They used a standard procedure, which contained 30 200-foot (60.96 m) lines that were randomly oriented along 45-degree azimuths.

Safranyik and Linton (1987) used line intersect sampling to estimate mean density of stumps and mean bark area per hectare for stumps. Their work demonstrated wider applications of line intersect methods.

Curran and Thompson (n.d.) carried out a grid-point-intercept method for measuring soil disturbance after logging in the province of B.C.. Their method is actually a line intersect sampling with systematic samples.

Simulation

To verify line intersect sampling methods, most researchers used field trials. However, Pickford and Hazard (1978), and Hazard and Pickford (1986) took advantage of computer simulation. They used a computer simulation to generate artificial populations of randomly and non-randomly distributed and orientated logging residue. They then tested simple random line intersect sampling and systematic grid line intersect sampling in their 1978 and 1986 studies.

Pickford and Hazard (1978) found that: (1) for sample lines of equal length, population variance estimated from repeated trials decreases with increases in total sample line length; (2) when maintaining a set level of precision, the product of the number of lines times line length is approximately constant; and (3) estimates of population variance change directly in proportion to changes in mean value (volume or pieces) per unit area.

Hazard and Pickford (1986) compared systematic grid sampling with SRS using one, two and three transects with systematic and random orientations. They further pointed out that: (1) line transects with random orientation produced unbiased estimates for both SRS and systematic grid sampling using one, two or three transects; (2) for a fixed total cost, systematic sampling using two or three lines per point is more efficient; and (3) when the total cost and total sample length are fixed, using longer length transects (61.0 m) is more efficient than using shorter length transects (30.5 m).

Problem

Line intersect methods are unbiased in theory, but from a practical point of view, these methods still have some problems. Howard and Ward (1972) and Pickford and Hazard (1978) indicated that the line intersect methods require extensive field work to achieve high levels of precision (more than 15 percent). Van Wagner (1982) summarized that line intersect methods are simple in theory, but complex in practice. Some factors which affect precision of estimation include: non-random piece orientation, slope of pieces in relation to the horizontal, non-circular cross section in diameter measurements, ground slope and difficulty in achieving the required total sample length in small cutovers.

People have tried various sample designs to reduce the piece orientation error, such as random directional lines (Howard and Ward 1972, Pickford and Hazard 1978), two lines placed at right angles (Van Wagner 1968), L-shaped transects (Howard and Ward 1972, Hazard and Pickford 1986), three lines at sixty degree angles to form an equilateral triangle (Van Wagner 1968, Ley 1984) and at 120 degrees angles (Hazard and Pickford 1986), and four crossed lines (Pulkki 1978). But random directional lines may be difficult to lay out when the line sample is quite long and the use of multiple short lines may lose the advantages provided by long narrow plots.

On the other hand, methods for verifying line intersect methods were not without problems. Most work was conducted in specific and unrepeatable situations. Few repeatable studies used computer-simulated populations (Pickford and Hazard 1978, Hazard and Pickford 1986). Real populations in northeastern Ontario may not be distributed in the same manner as simulated populations. Therefore, computer simulation using real populations to further test line transect designs may reveal more practical results.

In addition, there is no evidence of research focused on populations with low densities of residue. Previous researchers used fairly large amounts of residue in their work, such as 76.4 m^3/ha (Van Wagner 1968), 56.0 m^3/ha to 249.3 m^3/ha (Pickford and Hazard 1978) and 134.4 m^3/ha to 135.8 m^3/ha (Hazard and Pickford 1986). The only study where relatively low volumes of residue were sampled was conducted by Warren and Olsen (1964). They gave the length of sample line required for a 10 percent coefficient of variation when sampling in populations with various intensities of waste as listed in Table 2-1.

Table 2-1. Total transect length required to provide 10 percent levels of variation of estimates for various densities of residue.

Waste density (m^3/ha)	14	21	28	35	42
Total length of transects(m)	3259	2173	1629	1308	1086

Unfortunately, they did not give the total cutover areas for estimating the sample line lengths so that we do not have any idea about the sampling intensities used. However, comparing the waste density we find that the total sample length is inversely proportional to the waste density. This indicates that large samples are required for surveys where the amounts of residue are very low.

Since previous studies have found the line intersect method to be much more efficient in residue sampling, there has been little interest recently in use of plots or narrow strips. However, the information gained from one line may be less than that from a narrow strip and the search time in the strip may not be increased significantly over that required for the line intersect. Therefore, it is time to try some different enumeration methods.

In general, previous authors (Warren and Olsen 1964, Van Wagner 1968, Bailey 1970, Howard and ward 1972, De Vries 1974, Pickford and Hazard 1978, Pulkki 1978, Hazard and Pickford 1986) noted that logging residue might be distributed in clustered patterns. The degree of clustering found in residue populations was not given. For clustered populations, stratification of the populations into relatively homogeneous strata could lead to increases in precision for estimates of residue volumes. Van Wagner (1968) suggested stratification by size class (diameter or length) of individual residue pieces to increase precision. No evidence of stratification of sample units within these populations was given in the literature.

In summary, although it is known that residue amounts are important to the precision levels achieved by line intersect sampling (Warren and Olsen 1964, Pickford and Hazard 1978), sampling in very low density residue populations has not been explored. Sampling requirements in relation to the degree of clustering in residue populations has not been adequately identified. Finally, the potential gains to be made by stratifying residue populations according to density of residue has not been examined. These aspects are evaluated in this study.

CHAPTER THREE: PROJECT METHODOLOGY

Based on the literature review, we know that residue surveys have to use sampling methods to save time and costs. For developing a good residue sampling method, several commonly used residue survey methods and some new attempts have to be carried out for comparison. The fastest, and most practical and economic way to conduct comparisons is to use real cutover populations for conducting computer simulations. To ensure the simulation results are unbiased, we have to conduct probability sampling in sample frames derived from real populations. Since this project attempts to find methods for use in small cutover areas at the district level, large-scale photography is not preferred. Only ground-level survey methods which can be applied during cutover inspections will be considered in this study.

In order to meet the objectives of the project, several steps were required. Real population data, within various types of cutover conditions, were collected from northeastern Ontario for testing different sampling designs. Spatial pattern analysis was carried out to identify the differences among the cutovers. Computer simulation methods were applied for repeated residue sampling using various sampling designs and different sample units. Comparisons of precision of estimation for the densities and volumes of residue were made between designs.

DATA COLLECTION AND POPULATION DESCRIPTIONS

Cutover Type

Different methods of logging in various stand compositions and site types may result in different types of logging residue, and its distribution and orientation. The clearcut cutover types analyzed in northeastern Ontario may be divided into two main categories as shown in Table 3-1.

Table 3-1. Cutover types analyzed in northeastern Ontario.

Species	Site	
(group)	Wet	Dry
Jack pine	x	W/S
Black spruce	W	S

Note: x means not applicable,
W means winter season,
S means summer season.

Two logging methods were sampled for each combination given in Table 3-1, full tree and tree length (Ft/Tl). Thus, a total of 8 population types were examined in the study.

Data Collecting Method

Recent clearcut cutovers, which were representative of the various types to be sampled in northeastern Ontario were chosen by the OMNR in accessible areas.

Within each cutover, a sample area or real population was established. The boundary of the population was at least 10 m from roads and edges of adjacent stands, landings and reserves. The exclusion area is shown as the buffer strip in Figure 3-1. Residue within the buffer strip and close to landings was not expected to be representative of the overall cutover conditions and therefore was excluded from the study. To include this edge effect would increase the complexity of simulation without adding significantly to the understanding of sampling techniques. Operationally these edge areas are treated separately by OMNR survey staff. The purpose of this study is not to investigate the aspects of boundaries or to estimate the edge effect, therefore the buffer areas as represented in Figure 3-1 were not chosen as the sampling areas for simulation.

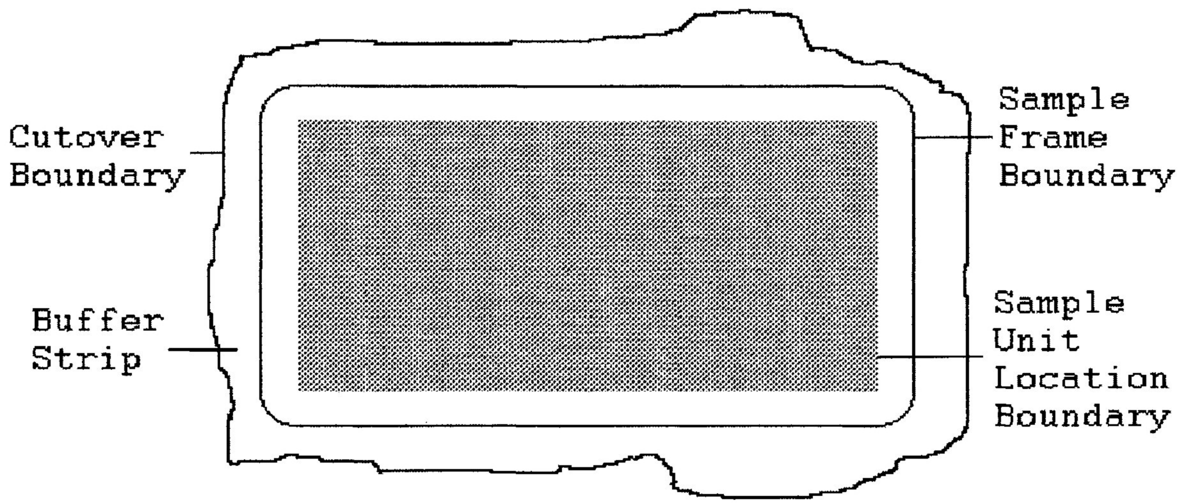


Figure 3-1. Relationship of sample frame and sample unit locations within cutovers.

For each cutover, the location, logging method, season of cut, stand type and site type were recorded for population classification. The sample area width and length were also recorded. A reference point used for developing a Cartesian co-ordinate system for mapping and to serve as the start of a baseline within each cutover was also established. Detailed cutover information was collected according to Table 3-2.

Table 3-2. Form for recording data applicable to each cutover.

CUTOVER:		SURVEY DATE:
CREW:		
SEASON OF CUT:	YEAR OF CUT:	LOGGING METHOD:
STAND TYPE:	SITE TYPE:	
CUTOVER LOCATION:		
DISTRICT:		
STAND NUMBER:		ORIENTATION:
LENGTH:	WIDTH:	SLOPE:
NUMBER OF SUBPLOT:		SUBPLOT SIZE:
CUTOVER MAP (SUBPLOT LOCATION):		

In order to record coordinate data easily for each piece of residue found within a cutover, the sample area was divided into 400 m^2 (20 m x 20 m) plots. In each plot, every sound merchantable piece of residue as defined by the OMNR was measured and recorded: i.e. pieces 2.5 m or longer with a top diameter greater than 10 cm. The location of the butt end and the orientation of each piece were also recorded. All standing residual trees which contained one or more logs of 2.5 m in length and with a top diameter of 10 cm or greater were tallied and recorded, too. All detailed residual information was recorded as shown in Table 3-3.

Table 3-3. Detailed tally sheet used to record data for each 400 m^2 plot.

DATE						CREW					
CUTOVER						SUBPLOT NUMBER					
#	Spp.	RES.	LO.	LA.	Db	H/L	D5.1	Dt	DEFECTS	AZIM.	COMMENT

where:

- \# = the order number of residue pieces,
- Spp. = species code,
- RES. = residue type including:
  - LOG ≥ 10 cm top diameter and ≥ 5.1 m in length,
  - TREE ≥ 2.5 m merchantable height and ≥ estimated 10 cm top diameter,
  - PULPWOOD ≥ 10 cm top diameter and ≥ 2.5 m in length,
- LO. = Y coordinate to the nearest 0.1 m,
- LA. = X coordinate to the nearest 0.1 m,
- Db = diameter at breast height to the nearest 0.5 cm,
- H/L = tree height or log length to the nearest 0.1 m,
- D5.1 = diameter at 5.1 meter point to the nearest 0.5 cm,
- Dt = top diameter to the nearest 0.5 cm,
- DEFECTS = defects of residue (OMNR 1985) for calculating merchantable volume,
- AZIM. = orientation of small end of log to the nearest 2 degrees,
- COMMENT = other information.

Population Description

Before simulating various sampling methods in the different populations, it was necessary to determine the biological and statistical characteristics of each population. The main characteristics consisted of the amount of residue, species, residue spatial pattern and orientation of each log.

The residue species proportions were easily obtained from the total amounts for each species. Percentages of the species indicated the residue compositions of each population.

Since opposite orientations for any piece had the same effect on line sampling, residue orientations greater than 180 degrees azimuth were reduced by 180 degrees. All azimuths were divided into groups (6, 12 or 18 degrees) in case too few pieces or no residue were counted at certain azimuths. The index of dispersion method was then used for comparing residue azimuth distribution patterns, and Green's index was used to measure the degree of clumping. Formulae for computing the index of dispersion (ID) and Green's index (GI) are listed as follows (Ludwig and Reynolds 1988):

$$ID = \frac{S^2}{\overline{X}} \tag{1}$$

$$GI = \frac{S^2/\overline{x} - 1}{n-1} \qquad (2)$$

where: $\bar{x}$ = sample mean of residue density,

S^2 = variance of the mean,

n = sample size.

To test the statistical significance of ID, value "d" was used when sample size was greater than 29, otherwise a Chi-square test was used (Ludwig and Reynolds 1988):

$$d = \sqrt{2x^2} - \sqrt{2(n-1)-1} \qquad (3)$$

where: $|d| <$ 1.96, for a random distribution;

$d <$ -1.96, for a regular distribution;

$d >$ 1.96, for a clumped distribution.

GI varies between 0 for a random pattern of spatial distribution and 1 for a pattern showing maximum clumping.

In order to detect individual residue distribution patterns, T-square index (C) was used. The formula for computing the index was defined by Ludwig and Reynolds (1988):

$$C = \frac{1}{N} \sum_{i=1}^{N} \frac{x_i^2}{x_i^2 + \frac{1}{2} y_i^2} \qquad (4)$$

where: x_i = the line length from the ith sampling point to the nearest individual sample element (tree or log),

y_i = the distance from the individual element to its nearest neighbour, lying beyond a line drawn through the element and perpendicular to the line from the sample point,

N = total number of sample points.

The value of C is approximately 1/2 for random patterns, significantly less than 1/2 for uniform patterns and significantly greater than 1/2 for clumped patterns.

For testing the significance of C, value Z was computed as:

$$Z = (c - 0.5)\left(\frac{1}{12N}\right)^{-\frac{1}{2}} \tag{5}$$

The critical Z value is obtained from a probability table for the standard normal distribution.

In order to detect both residue spatial location and orientation, two-term-local-quadrat-variance (ttlqv) and paired-quadrat-variance (pqv) were used. Formulae used for computing the variances are listed by Ludwig and Reynolds (1988) as:

$$TTLQV:\ VAR(x)_m = \frac{1}{N-2m+1}\left(\frac{1}{2m}\sum_{j=1}^{N-2m+1}\left(\sum_{i=j}^{M+j-1}(x_i - x_{i+m})\right)^2\right) \tag{6}$$

$$PQV: \quad VAR(x)_m = \frac{1}{N-m}\left(\frac{1}{2}\sum_{i=1}^{N-m}(x_i - x_{i+m})^2\right) \tag{7}$$

where: x_i = the number of individuals in the ith quadrat,

N = total number of quadrats,

m = block size, i.e., the number of quadrats per block, for TTLQV;

or spacing, i.e., the number of quadrats apart from each other, for PQV,

j = number of blocks.

Plots of the variances versus block sizes or spacings were drawn to show the spatial patterns of individuals within a population. The plots are interpreted as follows:

(i) variances randomly fluctuate for populations showing random patterns;

(ii) variances tend to minimize and not fluctuate for populations with uniform spatial patterns; and

(iii) variances tend to maximize at particular block sizes or spacings for populations with clumped spatial patterns.

SAMPLING TECHNIQUES

For various populations, different sampling methods could be chosen to perform efficient residue surveys. The methods of sampling used in this study for testing sampling configurations included SRS, systematic sampling, ratio estimates, random sampling (RS) with stratification, RS with poststratification and PPS sampling. Since most of the methods are standard procedures which can be found in statistics text books, only line intersect sampling (a case of PPS sampling), RS with poststratification and systematic sampling are discussed as follows.

Line Intersect Sampling

Line intersect sampling has been considered as a best method for surveying logging residue. It was also the primary method tested in this study. The sampling rule of the method for estimating the volume and number of pieces of logging residue using transects was given by De Vries (1974) as follows:

$$VOL_i = \frac{\pi^2}{8L_i}\sum_{j=1}^{n} nd_j^2 \tag{8}$$

$$LOG_i = \frac{10000\pi}{2L_i}\sum_{j=1}^{n} (n\frac{1}{l_j}) \tag{9}$$

$$VOL = \frac{1}{m}\sum_{i=1}^{m} VOL_i \tag{10}$$

$$LOG = \frac{1}{m}\sum_{i=1}^{m} LOG_i \tag{11}$$

where: VOL_i = volume per hectare of sample line i,
LOG_i = number of logs per hectare of sample line i,
VOL = average volume per hectare of m sample lines,
LOG = average number of pieces per hectare of m sample lines,
L_i = length of sample line i,
d_j = diameter of sample piece j at intersect point,
l_j = length of sample piece j,
n = number of sample pieces,
m = number of sample lines,
π ≈ 3.1415927.

When the lengths of sample lines are equal, the mean and variance of the mean can be estimated by SRS formulae (Cochran 1977) as:

$$\bar{x} = \frac{1}{m}\sum_{i=1}^{m} x_i \tag{12}$$

$$var\ \bar{x} = \frac{1}{m(m-1)}\sum_{i=1}^{m} (x_i - \bar{x})^2 \tag{13}$$

where: x_i = the volume of residue or number of logs per unit area at the ith observation,
$\bar{x}$ = the sample mean.

Otherwise, PPS sampling was used for selecting samples. Unbiased estimates of the mean volume or number of pieces of residue expressed as a ratio of residue per unit of line, and variance of this ratio (Cochran 1977) can be estimated as:

$$\overline{x} = R = \sum_{i=1}^{m} \frac{x_i}{L_i} \tag{14}$$

$$var\ \overline{x} = var\ R = \frac{1}{m(m-1)\ \overline{x}^2} \sum_{i=1}^{m} (x_i - RL_i)^2 \tag{15}$$

Where: R = a ratio estimator of the sample mean.

RS with poststratification

This project focused on small clearcut areas which were in most likelihood cut by a single crew using one logging method. This led to uniform areas of merchantable residue with no additional variables correlated to residue being available before surveys. Therefore multi-stage, multi-phase and other higher-order sampling techniques could not be applied. Stratified sampling could lead to increased precision, but it was very difficult to find factors for stratifying the small cutovers. Using residue volume or density to stratify the cutover could only be done during or after the survey.

A possible way to solve the problem is sub-population sampling. When using the residue volume or density as a factor to subdivide the population, only two sub-populations exist. One is areas containing residue, while the other is void or empty areas. Since only a few merchantable pieces were left on the ground, a large number of void plots were sampled by the above methods. If we can precisely determine the areas containing residue, stratified sampling should lead to higher sampling precision which is almost as precise as proportional stratified sampling (Cochran 1977). This poststratification method was tested and compared with the SRS.

Systematic Sampling

Systematic sampling was also tested for comparison. The basic methodology is similar to the method used in British Columbia for measuring soil disturbance (Curran and Thompson n.d.). A sample size of 35, 30 m transects with random orientation is recommended by the method. Formulae (12) and (13) are used for estimating mean of residue density and variance of the mean. This method assumes that randomly distributed populations are sampled.

METHODS FOR SCALING RESIDUE

Based on the literature review, three methods of enumerating residue elements within sample units were considered for testing: partial logs, butts only and cross-sectional area of intersection.

Line Intersect Method

In the line intersect method, all pieces of residue which intersect the sample lines are tallied. If a sample line crosses the end of a piece (Van Wagner 1968): (1) tally only if the central axis is crossed; and (2) tally every second such piece if the central axis touches the sample line exactly. Any piece whose central axis coincides with a sample line or is perpendicular to the radius of a circular sample transect is ignored. The length of each piece and its diameter at the intersect point are recorded. Formulae (8) to (15) were used for estimating the volumes and density of residue, provided one systematic sample is selected from randomly distributed population.

"Butts Only" Scale Using Plots

A simple way to understand the "butts only" method is to imagine that we let all residue pieces stand up and count them as we would in a conventional forest inventory plot. Therefore only those pieces with the butt end lying within a sample plot are counted. Those with butt ends lying outside the sample plots are not counted. Formulae (12) and (13) were used for estimating the volumes and density of residue using the "butts only" scaling method.

Partial Logs Scale Using Plots

This method is also easy to apply. Only the log portion lying inside a sample plot is measured. All other segments of the piece of residue are ignored. Identifying partial pieces of residue lying within square or circular plots will increase sampling time. This process may not increase costs on narrow strip plots due to expected shorter search times.

There are no special formulae for the partial logs method to estimate volume or number of pieces. Formulae (12) and (13) were used to estimate residue volumes and densities and their variances.

SAMPLING FRAME AND POPULATION BOUNDARY

A sample frame for a finite population of logging residue is a set of regular shaped, non-overlapping sample units (strips or square plots) within a cutover. The sample frame for an infinite population is defined as lines, or other sample units allowing overlapping of the units. The relationship between a sample space and the sample frame contained within the space are shown as Figure 3-1. All sample unit locations (i.e. centres) were randomly chosen with replacement from the shaded area (Figure 3-1) and were at least 1 m from each other. This prevented sample units from extending beyond the sample space. The orientation of each sample line was also randomly selected. The width of the blank zone, in Figure 3-1, represents one half of the length of a sample line or square plot, or the radius of a circular plot.

Since residue located in the blank zone of Figure 3-1 has a lower probability of selection than the shaded area, changing the width of the blank zone may result in different mean values for the same total area. However, for most sampling situations, the area of the blank zone will be small compared to the shaded area, leading to small differences in the mean estimates from alternate sample frames.

When the residue distribution pattern in a cutover is random, the density of residue can be expected to be equal in both the blank and shaded areas. In this condition, comparisons between sample frames with different shaded areas should lead to consistent estimates.

When comparisons are made between sampling methods and sample frames with clustered residue distributions are sampled, the different sampling methods will sample different sample areas and therefore produce different residue estimates. In this case, the sample frames should be adjusted to include equal sized shaded areas. This will lead to comparable estimates.

SIMULATION METHOD

Monte Carlo simulation methods are often used to obtain information on the bias and precision to be expected when applying a sampling methodology of unknown characteristics within a particular population (Murchison 1984). The method can be described as follows:

1. Define the sample frame for the population.

2. Select a set of random samples according to the selection criteria of the sample rule and compute the sample mean and variance. Repeat the process a second time.

3. Average the two means and two variances, select a third set of samples and compute average values of the three means and the three variances.

4. If the difference between the new (based on n random samples) and old average estimates (based on n - 1 random samples) for the mean or variance varies by more than some acceptable limit, select an additional set of samples and go to step 3. Otherwise stop the simulation.

Although simulation is a time consuming procedure, it is very useful for estimating the characteristics of an unfamiliar sample rule in a particular population. When computer simulations are conducted in a set of small, real populations, it is not necessary to obtain estimates of the characteristics for the populations. However, in this study, computer simulations had to be carried out in infinite sample frames, such as those defined by using line transects. Therefore, the objectives of the simulation were to:

(1) estimate the mean and variance for sample rules resulting in finite and infinite sample frames; and

(2) use computerized Monte Carlo methods for repeated sampling within these sample frames to simulate field trials.

When the value per sample unit for all members of a finite sample frame are known, the effect of sample size on the estimation of the mean and the standard error for a rule applied to the frame can be calculated. From sampling theory, the mean based on random sampling is an unbiased estimator of the population mean (Cochran 1977). The variance of the sample mean can be calculated according to Cochran (1977) as:

$$var\ \bar{x} = \frac{(1-f)}{n(N-1)} \sum_{i=1}^{N} (x_i - \bar{X})^2 \qquad (16)$$

where: N = the total number of sample units in the sample frame,

n = the number of sample units in the sample,

f = n/N, and 1-f is the finite population correction factor,

$\bar{X}$ = the mean of the sample frame,

x_i = the value of the ith observation.

This formula was used for comparing different finite sample frames within each population so as to decide which sample frame had the lower variance of the mean when n and N were fixed.

Simulation within the finite sample frames produced estimates for the mean and the variance of the mean when estimating residue density and volume. The simulation results from the finite sample frames were used as guides for defining sample intensity and unit size for simulations conducted in the infinite sample frames. Only residue density was estimated in the latter case.

SIMULATION PROCEDURE

For the finite sample frames, circular plots, square plots and narrow strips were considered. The sample size and plot size were also varied. This allowed full testing of how plot shape and size affect the sampling precision.

For methods using infinite sample frames, simulations were focused on line intersect methods. There were four kinds of line sample designs considered in this study: one line, two crossing lines, a triangle, and the circumference of a circle. The circular line can be treated as a polygon whose side lengths are equal to zero.

Finite Sample Frames

1. SRS for square plot

The plot size was changed in order to find the sample unit size which optimized sampling intensity for a particular population and met an acceptable level of error (Cochran 1977). Although the square plot methods are not recommended for residue sampling, they can be used for the purpose of comparison.

The SRS estimation formulae (12) and (13) were used to compute mean and variance of residue volume and density.

2. PPS ratio estimation for unequal length strip

The method can be described as follows:

(1) Divide the whole cutover into equal width strips which are perpendicular to one easily accessible base line, such as a road;

(2) Record the length for each strip and the total length of all strips placed in the sample frame;

(3) Use list sampling (PPS) based on strip area or length to select individual sample strips. The longer the strip, the more likely it is to be selected;

(4) Tally residue according to the butts only or partial logs scaling methods within each strip; and

(5) Use ratio estimation, formulae (14) and (15) with the finite population correction factor to calculate the mean

volume or density of residue per hectare, and the variance of the mean.

3. SRS for equal length strip

Define a regular shaped area within each cutover as a new population. Divide each new population into equal length strip sample units. Select sample strips by the SRS rule. Use formulae (12) and (13) with the finite population correction factor to estimate mean residue and variance of the mean. Sample frames were changed by altering the strip width or altering the strip length. Comparisons among various sample frames were then made.

4. SRS for circular plot

In this study, SRS of circular plots with replacement was used. Since sample size is relatively small compared with the number of plots in a sample frame, overlapping of plots could occur. The mean and variance estimates for the circular plots were computed using formulae (12) and (13).

5. SRS for finite line sample

Line intersect methods were used for comparison with strip sampling. Sample frames consisted of a finite number of equal length lines, which were located in the middle of the strip plots. Formulae (8) to (13) were used for estimation of the mean and variance for this method.

Infinite Sample Frame

The estimates for the mean and its variance for infinite sample frames are calculated using formulae (12) to (15).

Different configurations and lengths of lines were used for analyzing the sampling effects of arbitrary sample units which are transects. However, the comparison between the methods were all made based on a 30 m line length. All possible practical sample shapes that could be tested include:

1. single transects;
2. two-transects bisecting each other at 90 degrees (double transect);
3. triangular-transect forming an equilateral triangle; and
4. circular transect.

All transect designs, except the circular one, were randomly oriented.

SAMPLING TRIALS

Computer simulations used in this study produced average results from several thousand repeated sampling runs. These results may be expected to differ from the real sampling results. In order to find if the proposed residue sampling methods were applicable, several computer simulated sampling trials were also conducted. These included SRS (using butts only and partial logs plots), SRS and systematic sampling (using single, double, triangular and circular transects), RS with stratification (using long narrow strips) and RS with poststratification (using butts only and partial logs circular plots, and using circular transects). In order to avoid sampling error, several replications were conducted for each sampling method. All computer simulated sampling trials were independent of each other.

ANALYSIS OF RESULTS

Since different sample frames can be derived from the same population by changing the sample design or by altering the sample unit size, the sample variance generated by the various sample frames can be expected to vary. In order to compare different sampling designs and various sample unit sizes, a set of standard values of estimation should be used.

Accuracy of Estimation

For evaluating sampling accuracy, the maximum relative error of the estimated mean can be used and is calculated by:

$$re = \left| \frac{\bar{X} - \bar{\bar{X}}}{\bar{\bar{X}}} \right| \tag{17}$$

where: re = relative error of mean,

$\bar{x}$ = sample mean,

$\bar{X}$ = population or sample frame mean.

This relative error indicates the relative difference between the estimated mean and the real mean. If considered too large, this item is often called relative bias. It can be used for comparisons of sampling methods within and between populations or sample frames.

Sampling Precision

This study used the coefficient of variation of the sample mean (cv) to compare sampling precision among populations or sample frames with different means. The relative value is calculated by:

$$cv = \frac{s_{\bar{x}}}{\bar{\bar{x}}} \tag{18}$$

where: $s_{\bar{x}}$ = standard error of sample mean.

The relative precision (Loetsch *et al.* 1973) for estimated mean is defined by:

$$rp\,\% = \frac{t\,s_{\bar{x}}}{\bar{\bar{x}}} * 100 \tag{19}$$

where: rp = relative precision,

t = student's t value.

Sampling intensity

Sampling intensity (SI) or sampling proportion is a good value to asses the efficiency of a sample design and a sample frame. For example, using 100 0.01 ha sample plots has the same SI as using 50 0.02 ha sample plots, but these two samples may lead to different estimates for variance. When sampling to achieve a predetermined level of precision, the smaller SI a method requires, the better the method is. Therefore, SI was used in this study for the purpose of comparing sampling methods. SI is calculated as:

$$SI = \frac{n}{N} \tag{20}$$

where: n = sample size,
N = total number of sample units in a finite sample frame.

N is known in a finite sample frame and n can be obtained by the following formulae (Cochran 1977):

$$n = \frac{n_0}{1 + \frac{n_0}{N}} \tag{21}$$

$$n_0 = \left(\frac{tS}{r\bar{\bar{X}}}\right)^2 \tag{22}$$

$$r \le \left| \frac{\bar{x} - \bar{X}}{\bar{\bar{X}}} \right| \quad ; \quad \bar{X} > 0 \tag{23}$$

where: n_0 = the first approximation of sample size n,

S = standard deviation of population units,

r = allowable error.

CHAPTER FOUR: RESULTS

DATA COLLECTION

Two study areas were located in the boreal forest zone of northeastern Ontario. In each, cutovers to be used in the study were subjectively selected by the OMNR. Cutovers were sampled in Gogama District, where the major species is jack pine (*Pinus banksamea* Lamb.)(Pj). Cutovers were also surveyed in Hearst District, where black spruce (*Picea mariana* (Mill.) BSP.)(Sb) is the dominant merchantable species.

Due to limited budget, time and accessibility of cutovers, it was difficult to find all types of cutovers. The cutovers surveyed were provided by the OMNR and are listed in Table 4-1.

Table 4-1. Cutover type.

Cutover	Dominant Species	Logging System	Cut Season
CROTHERS	Pj	Mechanized[a] full tree	WINTER
DUBLIN	Pj	Conventional[b] full tree	WINTER
PAUDUSH	Pj	Conventional[b] full tree	SPRING
BANNERMAN	Sb	Mechanized[a] full tree	WINTER
GILL	Sb	Conventional[b] full tree	SPRING

a Mechanized = feller buncher felling and grapple skidder.
b Conventional = chain saw felling and cable skidder.

The total surveyed area is 42.4 ha. A total of 1060 plots (20 X 20 m) were sampled in 14 areas distributed in six different cutover types. Cutover sizes and plot distributions are summarized in Table 4-2.

Table 4-2. Cutover area and location.

District	Location	Area (ha)	Number of Plots
GOGAMA	CROTHERS-1	5.04	126
GOGAMA	CROTHERS-2	1.20	30
GOGAMA	DUBLIN-1	5.00	125
GOGAMA	DUBLIN-2	2.16	54
GOGAMA	PAUDUSH-1	4.16	104
GOGAMA	PAUDUSH-2	3.84	96
HEARST	BANNERMAN-1	4.16	104
HEARST	BANNERMAN-2	0.88	22
HEARST	BANNERMAN-3	1.00	25
HEARST	BANNERMAN-4	0.96	24
HEARST	GILL-1a	1.60	40
HEARST	GILL-1b	7.04	176
HEARST	GILL-2	2.40	60
HEARST	GILL-3	2.96	74
Totals		42.4	1060

DATA PROCESSING

Combined Cutover Data

Usually, each cutover was logged using only one logging method and system in one season, and covered similar stand composition. However, sample areas within one cutover may have different amounts and distribution patterns of residue. Therefore, before combining sample areas, differences of residue species composition and density had to be tested. Chi-square tests (Berenson and Levine 1983) were conducted for this purpose (see Appendix A).

Because the Dublin-1 cutover was a few kilometres away from the Dublin-2 cutover, these two were not combined. In contrast, Paudush-1 and Paudush-2 cutovers could be combined since they were only divided by a 20 m wide road and were only recorded separately for convenience. Cutovers Gill-1, Gill-2 and Gill-3 were surveyed in the same area. The Gill-1 cutover included two obvious types; Gill-1a was close to a road and did not contain standing trees, while the Gill-1b cutover contained many more standing trees. Hence, only Gill-1a, Gill-2 and Gill-3 cutovers were considered for aggregation. The chi-square test for the Gill area indicated that there were no differences between cutovers Gill-1a, Gill-2 and Gill-3.

The Chi-square test result for the Bannerman area showed that only Bannerman-1 and Bannerman-4 cutovers were the same type. The combined cutovers for simulation purpose are listed in Table 4-3.

Table 4-3. Populations for simulation.

Cutover	New Name	Dominant Species	Area
CROTHERS-1	CROTHERS	Pj	5.04
DUBLIN-1	DUBLIN	Pj	5.00
PAUDUSH	PAUDUSH	Pj	8.00
BANNERMAN-1&4	BANNERMAN	Sb	5.12
GILL-1b	GILL-1	Sb	7.04
GILL-1a&2&3	GILL-2	Sb	6.96

Calculating Residue Volume

Individual log volumes were calculated using Smalian's formula (Husch *et al.* 1982) and standing tree volumes were computed with formulae from Honer *et al.* (1983).

POPULATION CHARACTERISTICS

Residue Proportion

The species symbols used in this study are defined in Table 4-4. The residue frequencies classified by species and residue type are listed in Tables 4-5a to 4-5f.

Table 4-5 (a-f) indicate that: (1) the major residue type for the Dublin and Paudush cutovers was logs; (2) Crothers, Bannerman and Gill-1a, 2 and 3 cutovers contained more pulpwood than logs and; and (3) the proportions of logs and pulpwood were similar in the Gill-1b cutover.

Table 4-4. Symbol of some commercial tree species.

Common Name	Botanical Name	Symbol
Jack pine	*Pinus banksiana* Lamb.	Pj
Black spruce	*Picea mariana* (Mill.) B.S.P.	Sb
Poplar	*Populus* L.	Po
White birch	*Betula papyrifera* Marsh	Bw
White spruce	*Picea glauca* (Moench) Voss	Sw
Eastern white pine	*Pinus strobus* L.	Pw
Balsam fir	*Abies balsamea* (L.) Mill	B
Maple	*Acer* L.	Ma
Larch	*Larix* Mill.	L
Eastern white cedar	*Thuja occidentalis* L.	Ce

Table 4-5a. The number of pieces of logging residue found in Crothers-1 cutover.

Species	Pj	Sb	Po	Bw	Sw	Pw	B	Ma	L	Ce	Total
Log	147	68	1	9	4	0	1	0	1	0	231
Tree	3	8	0	1	0	0	0	0	0	0	12
Pulpwood	182	195	1	0	9	0	5	0	0	0	392
Stump	49	8	0	1	0	0	1	0	0	0	59
Sum	381	279	2	11	13	0	7	0	1	0	694
Sum/ha	76.	55.	0.	2.	3.	0.	1.	0.	0.	0.	137.7

Table 4-5b. The number of pieces of logging residue found in Dublin-1 cutover.

Species	Pj	Sb	Po	Bw	Sw	Pw	B	Ma	L	Ce	Total
Log	88	8	75	83	6	0	2	4	0	0	266
Tree	1	2	135	76	2	0	0	3	0	0	219
Pulpwood	39	2	0	11	4	0	0	2	0	0	58
Stump	96	0	2	4	1	0	0	0	0	0	103
Sum	224	12	212	174	13	0	2	9	0	0	646
Sum/ha	45.	2.	42.	35.	3.	0.	0.	2.	0.	0.	129.2

Table 4-5c. The number of pieces of logging residue found in Paudush cutover.

Species	Pj	Sb	Po	Bw	Sw	Pw	B	Ma	L	Ce	Total
Log	118	31	88	3	12	0	1	0	18	0	271
Tree	0	0	81	5	0	0	0	0	41	0	127
Pulpwood	84	50	2	0	2	1	0	0	1	0	140
Stump	1	1	1	0	1	1	0	0	0	0	5
Sum	203	82	172	8	15	2	1	0	60	0	543
Sum/ha	25.	10.	22.	1.	2.	0.	0.	0.	8.	0.	67.9

Table 4-5d. The number of pieces of logging residue found in Bannerman-1&4 cutover.

Species	Pj	Sb	Po	Bw	Sw	Pw	B	Ma	L	Ce	Total
Log	0	131	2	1	0	0	0	0	1	0	135
Tree	0	10	1	0	0	0	0	0	0	0	11
Pulpwood	0	299	0	0	0	0	0	0	0	0	299
Stump	0	3	0	0	0	0	0	0	0	0	3
Sum	0	443	3	1	0	0	0	0	1	0	448
Sum/ha	0.	87.	1.	0.	0.	0.	0.	0.	0.	0.	87.5

Table 4-5e. The number of pieces of logging residue found in Gill-1B cutover.

Species	Pj	Sb	Po	Bw	Sw	Pw	B	Ma	L	Ce	Total
Log	0	233	73	21	0	0	13	0	14	37	391
Tree	0	2	80	9	0	0	0	0	7	33	131
Pulpwood	0	234	2	0	0	0	48	0	3	16	303
Stump	0	4	1	0	0	0	0	0	0	0	5
Sum	0	473	156	30	0	0	61	0	24	86	830
Sum/ha	0.	67.	22.	4.	0.	0.	9.	0.	3.	12.	117.9

Table 4-5f. The number of pieces of logging residue found in Gill-1a&2&3 cutover.

Species	Pj	Sb	Po	Bw	Sw	Pw	B	Ma	L	Ce	Total
Log	1	172	12	1	0	0	0	0	12	1	199
Tree	0	13	1	0	0	0	0	0	0	0	14
Pulpwood	0	382	2	1	0	0	11	0	0	5	401
Stump	0	1	0	0	0	0	0	0	0	0	1
Sum	1	568	15	2	0	0	11	0	12	6	615
Sum/ha	0.	82.	2.	0.	0.	0.	2.	0.	2.	1.	88.4

Spatial Pattern Analysis

Log Orientation Distribution

Since there is no residue orientation at certain specific azimuths, all residue orientations have to be classified into angle groups for detecting log orientation distribution. Three ranges using angles of 6°, 12° and 18° were used for classifying residue into frequency groups. Clustering indices were then calculated for each classification system using the index of dispersion and Green's index (Ludwig and Reynolds 1988).

The results of testing residue orientation patterns are listed in Table 4-6. In the table, ID is the index of dispersion, D is ID expressed as a t-statistic and GI is Green's index. The critical value for D at the 95 percent confidence level is 1.96. Indices with italics and underline indicate clustered distributions according to D being greater than 1.96.

Table 4-6. Residue orientation frequency analysis for three frequency groups.

6 Degree angle groups

	Total			Log			Pulpwood		
	ID[a]	D[b]	GI[c]	ID	D	GI	ID	D	GI
C.[d]	1.13	.56	.000	.98	.01	.000	*1.81*	*2.71*	*.003*[e]
D.	1.37	1.38	.002	1.35	1.31	.003	1.06	.28	.002
P.	1.37	1.35	.001	1.16	.64	.001	1.05	.24	.000
B.	.86	-.50	.000	.70	-1.16	-.004	1.18	.72	.001
G1	1.14	.57	.000	1.38	1.40	.002	.47	-2.33	-.003
G2	*2.22*	*3.80*	*.003*	*2.36*	*4.15*	*.010*	1.28	1.08	.001

12 Degree angle groups

	Total			Log			Pulpwood		
	ID	D	GI	ID	D	GI	ID	D	GI
C.	1.01	.13	.000	.98	.04	.000	1.79	1.89	.002
D.	1.48	1.25	.003	1.66	1.63	.005	1.00	.10	.000
P.	*1.83*	*1.97*	*.002*	1.44	1.15	.002	1.16	.50	.001
B.	.88	-.24	.000	.99	.07	.000	1.25	.73	.001
G1	1.15	.47	.000	1.38	1.03	.002	.43	-1.73	-.003
G2	*3.44*	*4.62*	*.006*	*3.21*	*4.29*	*.016*	1.74	1.78	.002

18 Degree angle groups

	Total			Log			Pulpwood		
	ID	D	GI	ID	D	GI	ID	D	GI
C.	1.19	.50	.000	.97	.06	.000	*2.48*	*2.56*	*.005*
D.	1.33	.77	.002	1.49	1.05	.004	.38	-1.50	-.018
P.	*2.35*	*2.38*	*.003*	1.47	1.01	.002	1.73	1.45	.006
B.	1.22	.56	.001	.81	-.31	-.002	1.30	.72	.001
G1	1.54	1.14	.001	1.89	1.71	.004	.47	-1.21	-.003
G2	*5.00*	*5.36*	*.009*	*4.16*	*4.53*	*.022*	*2.55*	*2.65*	*.005*

a. ID = index of dispersion.
b. D = t-statistic of ID and GI.
c. GI = Green's index.
d. C. = Crothers; D. = Dublin; P. = Paudush; B. = Bannerman; G1 = Gill-1; G2 = Gill-2.
e. Indices with italics and underline indicate clustered distributions.

If the residue orientation pattern indices from the three angle clustering groups are about the same, the residue is assumed to be randomly orientated. Therefore, Table 4-6 suggests that residue orientation shows random distribution patterns in most cutovers. Exceptions to this include a relatively low degree of clumping in the Crothers cutover for pulpwood, in the Paudush area for total residues, and in Gill-2 for all types of residues.

Residue Butt Distribution

Indices of spatial pattern distribution using the butts only method on six cutovers using the T-square distance method (Ludwig and Reynolds are given in Tables 4-7a, b and c. In these tables, C is the T-square statistic and Z is the C expressed as a standard normal deviate. Table 4-7a shows the spatial pattern for the original cutovers. Since sampling results are often related to size of a population to be sampled when sample size is fixed, using same or similar size of populations to test sampling methods is necessary. Therefore, all original cutovers were reduced to similar size of the Dulbin cutover, which is the smallest population (2.6 ha). Tables 4-7b and 4-7c indicate the spatial pattern for the reduced cutovers. The difference between Tables 4-7b and 4-7c is that the former contains all species and the latter contains dominant species only.

Table 4-7a. Results of spatial pattern analysis in original cutovers using the T-square method.

	Total		Log		Pulpwood		Sample Size
	C[a]	Z[b]	C	Z	C	Z	N
C.[c]	*.55*	*2.98*[e]	*.56*	*3.91*	*.57*	*4.36*	329
D.	.51	.51	.51	.63	*.55*	*3.18*	371
P.	.50	.11	*.57*	*4.51*	.50	-.03	389
B.	.51	.52	*.62*	*9.25*	.50	-.04	500
G1	*.53*	*2.41*	*.58*	*6.48*	.51	.52	500
G2	.51	.78	*.56*	*3.26*	.53	1.47	244

Table 4-7b. Results of spatial pattern analysis in reduced cutovers using the T-square method.

	Total		Log		Pulpwood		Sample Size
	C	Z	C	Z	C	Z	N
C.	*.58*	*5.77*	.52	1.74	*.61*	*8.34*	494
D.	.52	.83	.53	1.28	.52	1.16	193
P.	*.58*	*5.58*	*.59*	*6.76*	.52	1.46	454
B.	*.54*	*2.99*	*.63*	*9.43*	*.55*	*3.34*	447
G1	*.57*	*5.09*	*.62*	*8.82*	.52	1.69	476
G2	.52	1.05	*.58*	*4.38*	.52	1.16	242

Table 4-7c. Results of spatial pattern analysis in reduced cutovers with single dominant species using the T-square method.

	Total		Log		Pulpwood		Sample Size
	C	Z	C	Z	C	Z	N
C.	*.68*	*11.52*	*.59*	*5.98*	*.73*	*14.85*	362
D.	*.67*	*11.68*	*.67*	*11.65*	*.64*	*9.58*	407
P.	*.61*	*6.39*	*.70*	*11.80*	.51	.70	285
B.	.49	-.31	*.64*	*7.19*	.51	.65	233
G1	*.60*	*7.80*	*.68*	*14.23*	.52	1.45	500
G2	*.56*	*2.54*	*.58*	*3.69*	.56	.70	167

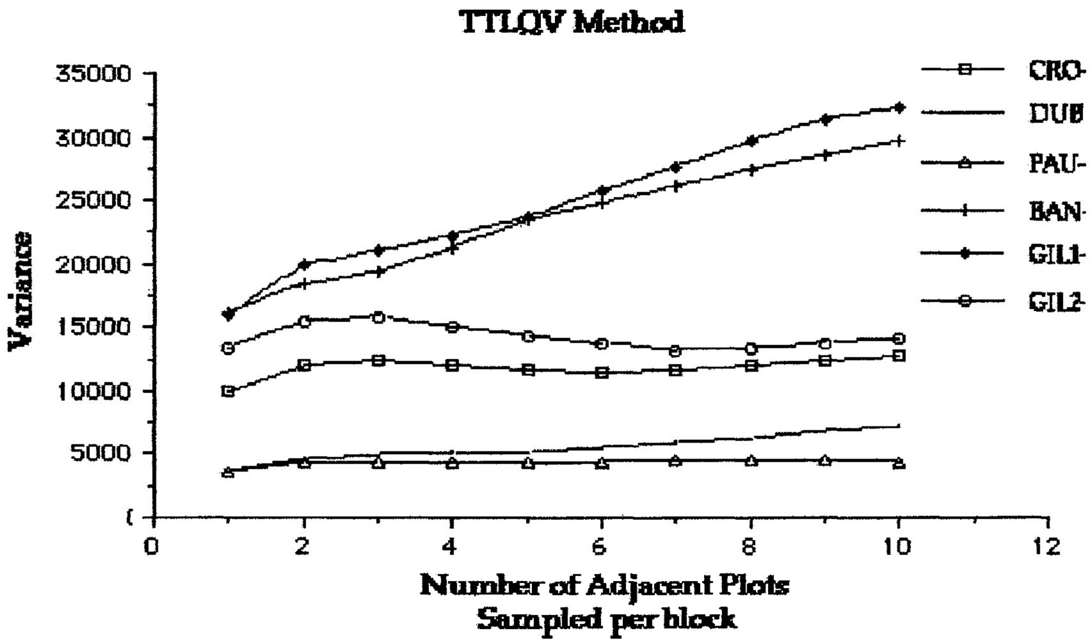
a. C = T-square index.
b. Z = standard normal deviate of C.
c. C. = Crothers; D. = Dublin; P = Paudush; B. = Bannerman; G1 = Gill-1; G2 = Gill-2.
e. Indices with italics and underlined format indicate clustered distributions.

All italic and underlined indices in Tables 4-7(a-c) indicate clumped residue butt distribution patterns. The numbers of clustered indices increased from Tables 4-7a to 4-7c. This tendency indicates that in smaller cutovers, or with lower residue densities, there is more clumping of the large pieces of residue.

When residue butt distribution indices in Tables 4-7(a-c) are compared with their cutover types in Table 4-1, no relationship between the indices and cutover types can be found.

Residue Distribution

Considering that any residue piece is defined by its location and orientation, two-term-local-quadrat-variance (TTLQV) and paired-quadrat-variance (PQV) methods were applied to detect the degree of clumping. Figure 4-1 shows the results of the quadrat-variance methods using a sample strip composed of 5 m square plots. The partial logs scale was used for calculating the residue values of the plots.



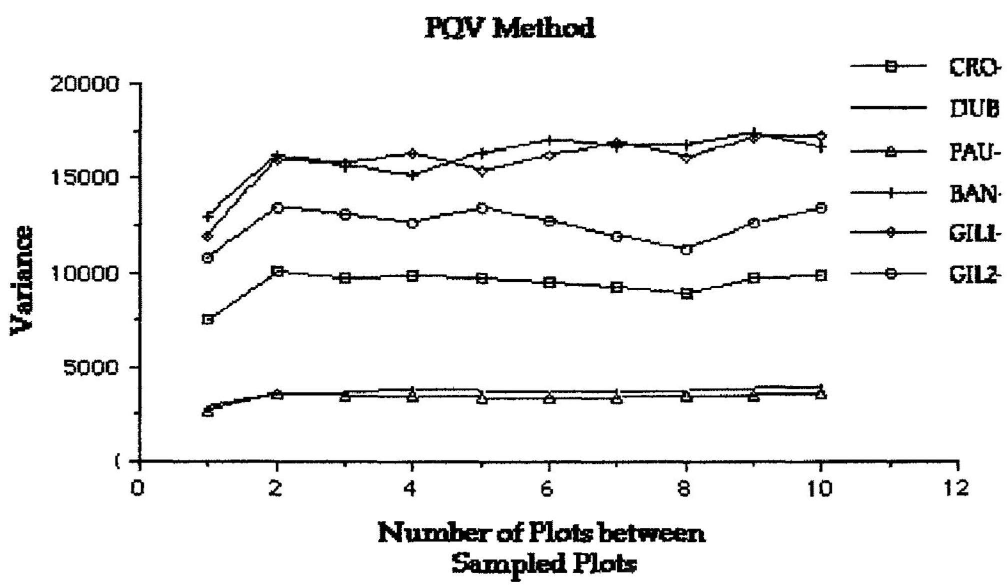
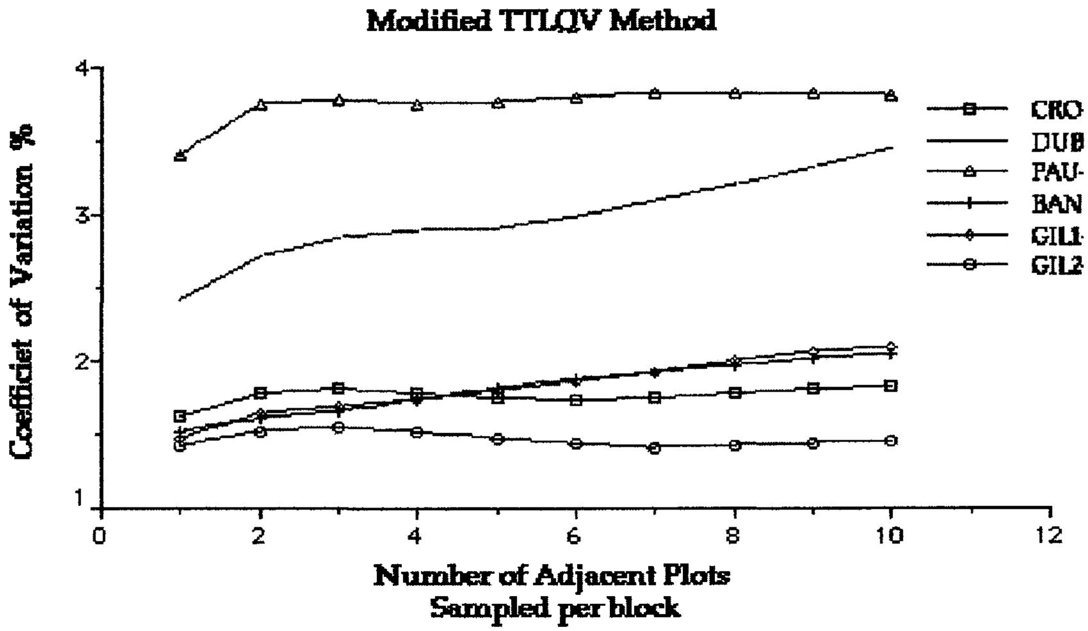


Figure 4-1. Spatial pattern analysis of log distribution in six cutovers using quadrat-variance methods (5m by 5 m plots).

Figure 4-1 indicates that: (1) all cutovers had a slightly clumped residue distribution; (2) the value of adjacent plots were similar; and (3) small mean values of residue density generally resulted in small variance estimates for this statistic.

Since the various cutovers showed different mean values, direct comparisons of variances may be misleading. Using the relative values of coefficient of variation for the means will provide more meaningful comparisons. Figure 4-2 is the modified results of Figure 4-1. It indicates that the mean value (volume or pieces per hectare) for a cutover is a very important factor of population variation. For populations having the same variance of the mean, a population with a small mean will have a bigger coefficient of variation. For example, the Paudush cutover showed the smallest and most uniform pattern variance in relation to plot size for all cutovers as shown in Figure 4-1. But in Figure 4-2, this cutover has the biggest coefficient of variation, which indicates a clumped distribution pattern.



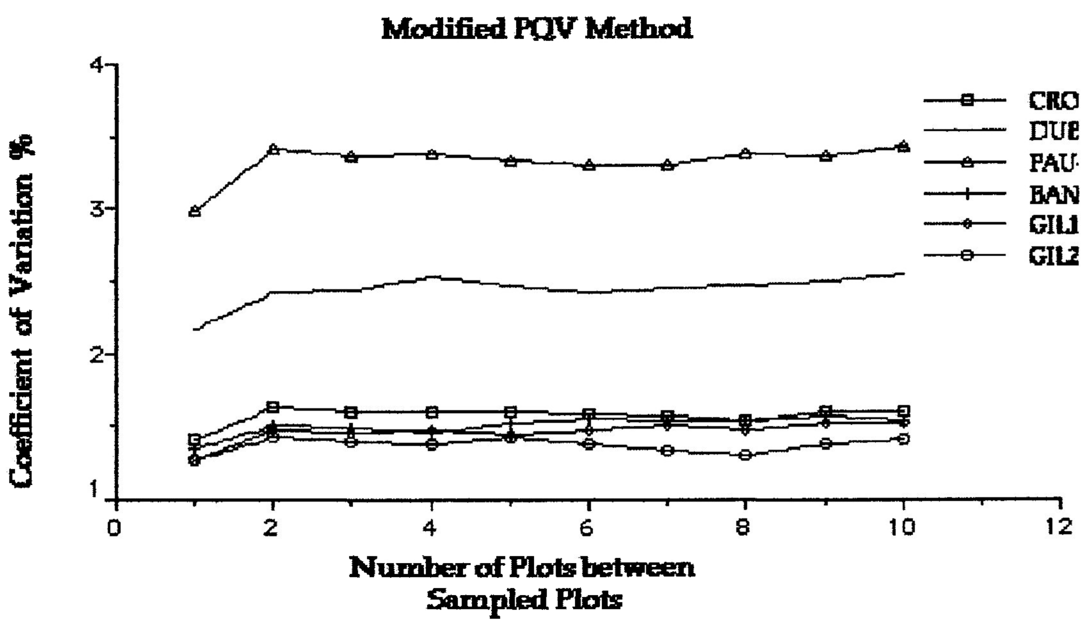


Figure 4-2. Modified results of quadrat-variance spatial pattern analysis in Figure 4-1.

POPULATIONS FOR SIMULATION

The characteristics of the populations are summarized in Tables 4-8 and 4-9. Logging method, cutting season and site condition were not included in these tables because the residue spatial patterns showed no relationship to these factors. Therefore, sampling simulation results were compared on the basis of population differences in degree of clumping, and mean volume or pieces of residue per hectare. The degree of clumping using the T-square index as given in Tables 4-8 and 4-9 is hard to interpret and only gives us a general idea about the clumping.

Table 4-8. Individual cutover characteristics: areas, pieces per hectare, residue clampers (T-square index) and residue orientation patterns (Index of Dispersion) in original cutovers.

	Characteristics			
Cutover	Area (ha)	Pieces (per ha)	T-Square Index	Index of Dispersion
CROTHERS	4.00	130.3	0.55	1.19
DUBLIN	2.56	63.3	0.51	1.33
PAUDUSH	7.92	50.9	0.50	2.53
BANNERMAN	3.80	83.2	0.51	1.22
GILL-1	4.00	110.5	0.53	1.54
GILL-2	5.40	81.5	0.51	5.00

Table 4-8 shows the characteristics for each population using regular shaped areas within the original cutovers. The table indicates that all populations showed clumped patterns of residue: Crothers and Gill-1 cutovers showed higher degrees of clumping in residue location; and Paudush and Gill-2 cutovers showed higher clumping in piece orientation.

Table 4-9a lists six populations of approximately the same size, which are suitable for comparison. When the population areas were reduced, the degrees of clumping were increased as shown in Table 4-9a.

Table 4-9b shows a set of population data where only the dominant species was considered. These populations showed large differences in the mean densities and in degrees of clumping.

Table 4-9a. Individual cutover characteristics: areas, pieces per hectare, and residue clumps (T-square index) for cutovers reduced to regular shaped areas.

	Characteristic		
Cutover	Area ha	Pieces per ha	T-square Index
CROTHERS	2.56	131.3	0.58
DUBLIN	2.56	63.3	0.51
PAUDUSH	2.64	46.2	0.58
BANNERMAN	2.60	85.0	0.54
GILL-1	2.60	123.5	0.57
GILL-2	2.56	90.6	0.52

Table 4-9b. Individual cutover characteristics for reduced areas measuring dominant species only.

Cutover	Characteristic			
	Species	Pieces (per ha)	T-Square Index	TTLQV & PQV Indices
CROTHERS	Pj	61.7	0.68	CLUMPED
DUBLIN	Pj	24.6	0.67	VERY CLUMPED
PAUDUSH	Pj	17.4	0.61	CLUMPED
BANNERMAN	Sb	84.2	0.49	VERY CLUMPED
GILL-1	Sb	86.2	0.60	VERY CLUMPED
GILL-2	Sb	81.6	0.56	CLUMPED

SIMULATION TRIALS

Simulation trials were carried out on the data sets for the three regular shaped areas of Crothers-1, Dublin-1, and Gill-1b cutovers. The purpose of the trials was to test computer programming, and to check sampling and simulation methods. The width of both equal and unequal length strips was 5 m, the sample size was fixed at eight strips and each trial was run 5000 times. The results are listed in Tables 4-10 (a-c) and 4-11 (a-b).

Table 4-10a presents simulation results when using unequal length strips. Both SRS and PPS sample rules produced similar estimates of the sample frame mean. The PPS sample rule produced consistently lower standard errors of means than the sample frame. By comparison, the SRS rule both over-estimated and under-estimated the sample frame error.

Table 4-10a. Results of simulation trials for estimating mean density of residue and standard error of the mean (se) using PPS and SRS ratio estimation for unequal length strips in original regular shaped cutovers.

Cutover	Sample Frame		Simulation			
			PPS		SRS	
	mean pieces/ha	se	mean pieces/ha	se	mean pieces/ha	se
CROTHERS	123.4	17.92	122.4	17.12	121.9	16.64
DUBLIN	64.8	9.36	65.2	8.64	64.6	9.52
GILL	98.6	14.80	97.2	14.24	98.4	14.80

Table 4-10b. Coefficients of variation (cv) of sample mean of simulation trials for unequal length strips applied to original regular shaped cutovers.

Cutover	Sample Frame	Simulation	
		PPS	SRS
	cv (%)	cv (%)	cv (%)
CROTHERS	14.52	13.99	13.65
DUBLIN	14.44	13.25	14.74
GILL	15.01	14.65	15.04

Table 4-10c. Relative errors (re) of estimated sample mean and standard error (se) for simulation trials using unequal length strips applied to original regular shaped cutovers.

Cutover	re (%)			
	PPS		SRS	
	mean	se	mean	se
CROTHERS	0.81	4.46	1.22	7.14
DUBLIN	0.62	7.69	0.31	1.71
GILL	1.42	3.78	0.20	0.00

Table 4-10b gives the results of Table 4-10a in terms of the coefficient of variation of the sample mean resulting from the simulation trials. In Table 4-10b, the estimated coefficients of variation of the simulation trials were very close to those of the sample frames. Table 4-10c lists relative errors for the estimated sample means and standard errors shown in Table 4-10a.

Tables 4-11 (a-b) show simulation results when using equal length strips and SRS. In Table 4-11a, the simulated means, standard errors of the means and coefficients of variation of the means are not exactly the same as, but very close to those of the sample frames. In Table 4-11b, the maximum relative error is less than 2 percent, which indicates precise results of simulations.

Table 4-11a. Results of simulation trials for estimating mean density of residue, standard error of the mean (se) and coefficients of variation (cv) of sample mean using SRS for equal length strips in reduced regular shaped cutovers.

	Sample Frame			Simulation		
Cutover	mean	se	cv	mean	se	cv
	Pieces/ha		%	pieces/ha		%
CROTHERS	130.3	16.88	12.95	128.5	16.96	13.20
DUBLIN	65.2	16.64	25.52	65.9	16.64	25.25
GILL	110.5	8.72	7.89	109.9	8.56	7.79

Table 4-11b. Relative errors (re) of estimated sample mean and standard error (se) for simulation trials using equal length strips in reduced regular shaped cutovers.

Cutover	re (%)	
	mean	se
CROTHERS	1.38	0.47
DUBLIN	1.07	0.00
GILL	0.54	1.83

Slight differences exist between the sample frame data (mean residue densities and standard error of mean) and their corresponding simulation estimates. In all cases, these differences are less than 9 percent. Therefore, these simulation trials indicate that the sampling and simulation methods were unbiased. If the simulations were to be run longer or with more random number sets, these small differences would be expected to decrease further.

SAMPLING IN FINITE SAMPLE FRAMES

Sampling intensity (SI) is used in this section as a criterion for comparison. Formulae (17) to (20) in Chapter Three were used for calculating SIs. All estimates of SI were calculated with 95 percent probability and 20 percent relative error of the sample frame mean. A smaller SI indicates a higher sampling precision.

Square Plot Sampling

Tables 4-12 (a-b) to 4-13 (a-b) present the results when using three plot sizes (25, 100 and 400 m^2) of the butts only and partial logs methods. Tables 4-12a and 4-12b reveal that the SI was very closely inversely related to the sample frame mean when residue spatial patterns were ignored. For example, although the Crothers cutover showed the greatest degree of clumping, it had a lowest SI because its mean density of residue was the largest. Also, the two tables show that sampling using smaller plots usually required lower sampling intensities. The results for Gill-2 are an exception to this trend.

Table 4-12a. Sample intensity required to meet 20 percent relative error using the butts only square plot sampling method in relation to residue density, sample frame and plot size for original cutover areas.

Cutover	Sample Frame Mean pieces/ha	Number of Sample Units	Plot Area m^2	SI %
		1600	25	17.9
CROTHERS	130.25	400	100	19.2
		100	400	25.0
		1024	25	40.2
DUBLIN	63.28	256	100	43.0
		64	400	48.4
		3168	25	20.8
PAUDUSH	50.88	792	100	20.5
		198	400	19.2
		1520	25	27.4
BANNERMAN	83.16	380	100	28.4
		95	400	34.7
		1600	25	21.9
GILL-1	110.50	400	100	25.2
		100	400	30.0
		2160	25	19.6
GILL-2	81.48	540	100	18.3
		135	400	15.6

Table 4-12b. Sample intensity required to meet 20 percent relative error using the butts only square plot sampling method in relation to residue density, sample frame and plot size for reduced regular shaped cutover areas.

Cutover	Sample Frame Mean pieces/ha	Number of Sample Units	Plot Area m^2	SI %
		1024	25	25.3
CROTHERS	131.25	256	100	27.3
		64	400	34.4
		1024	25	40.2
DUBLIN	63.28	256	100	43.0
		64	400	48.4
		1056	25	45.5
PAUDUSH	46.21	264	100	47.0
		66	400	48.5
		1040	25	34.8
BANNERMAN	85.00	260	100	36.9
		65	400	47.7
		1040	25	28.2
GILL-1	123.46	260	100	32.7
		65	400	38.5
		1024	25	32.4
GILL-2	90.63	256	100	28.9
		64	400	28.1

Figures 4-3 (a-c) give a visual description of the effect of changing population size and population mean on the SI when the sample plot area is fixed at 25 m². In Figure 4-3a, the populations on the larger cutover areas (Paudush, Gill-2) had smaller SI. When cutover areas were reduced to approximately equal sizes for comparisons, a very strong relationship between the population means and their SI was found (see Figure 4-3b). Figure 4-3c reveals that, when the cutovers had about the same mean values, a clumped area (Gill-1 cutover) required a higher SI than less clumped areas (Bannerman cutover).

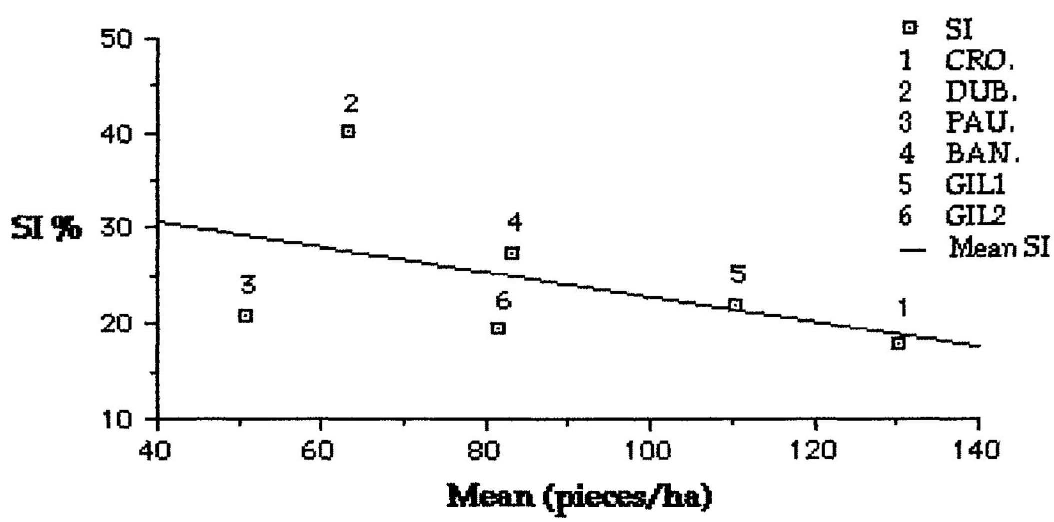


Figure 4-3a. Butts only square plot sampling intensity by population mean within original cutover areas.

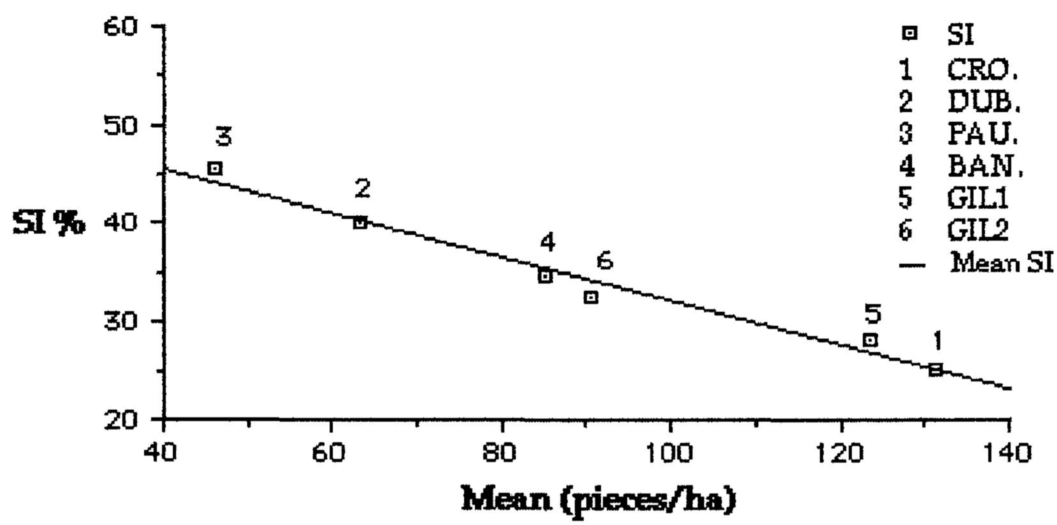


Figure 4-3b. Butts only square plot sampling intensity by population mean within reduced regular shaped cutover areas.

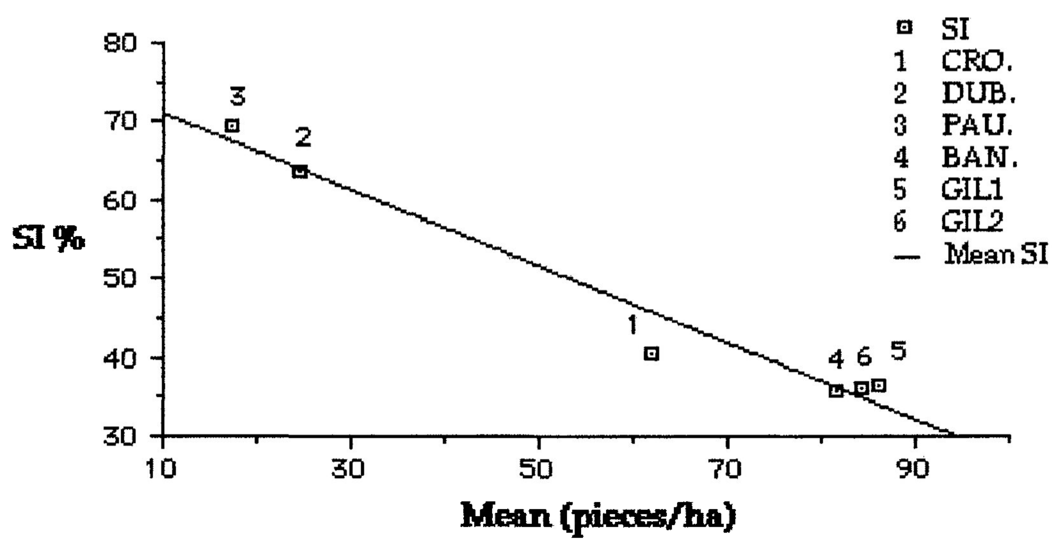


Figure 4-3c. Butts only square plot sampling intensity by population mean within reduced regular shaped cutover areas and measuring one species only.

When population clumping was increased through measuring only one dominant species, different results occurred as given in Table 4-13a. The table indicates that using smaller plots for butts only sampling did not always result in lower SI when the population is very clumped, such as in Crothers and Dublin cutovers.

When comparing the results in Tables 4-13a and b, it can be seen that for estimating residue density, measuring partial logs on plots gives better accuracy than measuring butts only. This is especially true for small plots, where 5 to 10 percent reductions in sampling intensity were realized.

Table 4-13b also shows a consistent trend where a reduction in plot size leads to a lower SI. In addition, when comparing populations where the mean residue densities are forced to be approximately equal, the population with a less clumped distribution (Gill-2 versus Gill-1) required a lower SI to meet fixed precision requirements.

Table 4-13a. Sample intensity required to meet 20 percent relative error using the butts only square plot sampling method in relation to residue density, sample frame and plot size for reduced regular shaped cutover areas with single dominant species.

Cutover	Sample Frame Mean pieces/ha	Number of Sample Units	Plot Area m^2	SI %
		1024	25	40.5
CROTHERS	61.72	256	100	43.0
		64	400	39.1
		1024	25	63.6
DUBLIN	24.61	256	100	62.5
		64	400	71.9
		1056	25	69.5
PAUDUSH	17.42	264	100	71.2
		66	400	71.2
		1040	25	35.1
BANNERMAN	84.23	260	100	37.3
		65	400	49.2
		1040	25	36.5
GILL-1	86.15	260	100	42.7
		65	400	52.3
		1024	25	35.7
GILL-2	81.64	256	100	32.0
		64	400	32.8

Table 4-13b. Sample intensity required to meet 20 percent relative error using the partial logs square plot sampling method in relation to residue density, sample frame and plot size for reduced regular shaped cutover areas with single dominant species.

Cutover	Sample Frame Mean Pieces/ha	Number of Sample units	Plot Area m^2	SI %
	60.91	1024	25	30.2
CROTHERS	60.91	256	100	36.3
	60.91	64	400	39.1
	24.17	1024	25	52.5
DUBLIN	24.17	256	100	58.2
	24.17	64	400	70.3
	16.25	1056	25	58.4
PAUDUSH	16.25	264	100	63.6
	16.25	66	400	68.2
	81.62	1040	25	29.5
BANNERMAN	81.37	260	100	37.7
	81.37	65	400	47.7
	84.34	1040	25	27.9
GILL-1	84.26	260	100	36.2
	84.21	65	400	47.7
	80.30	1024	25	27.6
GILL-2	80.30	256	100	30.1
	80.30	64	400	32.8

Tables 4-14 (a-b) list results from residue volume sampling when measuring butts only and partial logs on plots, respectively. Comparing results in Tables 4-13a and b with Tables 4-14a and b shows that volume sampling for residue required higher sampling intensities than density sampling. This is because the volume of a big piece will be many times larger than that of a small piece, leading to a large variation between pieces when estimating volume. When residue density per plot is low, as found in this study, the large differences in piece volumes translate to large variation among sample plot volumes. Also, the OMNR was only interested in the number of pieces of merchantable logging residue. Therefore, volume sampling was not carried out in the subsequent simulation and sampling trials.

Table 4-14a. Sample intensity required to meet 20 percent relative error using the butts only square plot sampling method in relation to residue volume, sample frame and plot size for reduced regular shaped cutover areas with single dominant species.

Cutover	Sample Frame Mean m^3/ha	Number of Sample units	Plot Area m^2	SI %
		1024	25	49.8
CROTHERS	3.9311	256	100	52.3
		64	400	46.9
		1024	25	73.6
DUBLIN	2.9792	256	100	71.9
		64	400	73.4
		1056	25	76.6
PAUDUSH	2.0811	264	100	78.4
		66	400	80.3
		1040	25	39.9
BANNERMAN	4.3945	260	100	42.7
		65	400	52.3
		1040	25	43.8
GILL-1	8.9215	260	100	50.8
		65	400	63.1
		1024	25	47.0
GILL-2	5.7762	256	100	45.7
		64	400	40.6

Table 4-14b. Sample intensity required to meet 20 percent relative error using the partial logs plot sampling method in relation to residue volume, sample frame and plot size for reduced regular shaped cutover areas with single dominant species.

Cutover	Sample Frame Mean m^3/ha	Number of Sample units	Plot Area m^2	SI %
	3.9018	1024	25	32.8
CROTHERS	3.9018	256	100	38.7
	3.9018	64	400	45.3
	2.9398	1024	25	60.2
DUBLIN	2.9398	256	100	66.0
	2.9398	64	400	76.6
	1.9933	1056	25	64.0
PAUDUSH	1.9933	264	100	72.0
	1.9933	66	400	77.3
	4.1795	1040	25	30.8
BANNERMAN	4.1785	260	100	40.4
	4.1785	65	400	50.8
	8.6827	1040	25	31.7
GILL-1	8.6742	260	100	41.5
	8.6670	65	400	55.4
	5.6585	1024	25	33.2
GILL-2	5.6584	256	100	41.0
	5.6584	64	400	40.6

<u>Strip and Line Sampling</u>

Figure 4-4 shows the simulation results from SRS when measuring butts only on strips within six approximately the same size populations, as described in Table 4-9a. Figures 4-5 to 4-8 illustrate the simulation results from original Crothers cutover, as described in Table 4-8. The results of other cutovers have a similar tendency to that of the Crothers cutover. Figures 4-5 to 4-6 show the results when changing strip orientation, and strip width and length, but for the Crothers cutover only. Figures 4-7 and 4-8 were used for comparing strip and line intersect sampling. In all figures, the number of sample units is the number of total sample units in a sample frame. This number was changed by narrowing the width or reducing the length of sample strips. Therefore, different numbers of sample units indicate different sample frame.

Figure 4-4 illustrates that SI was inversely proportional to the number of sample units in the sample frames. Also, when the number of sample units increased to a threshold point, the SI remained constant. For different populations, SI was approximately proportional to the population mean value. For example, the Crothers population and Paudush population had the same clumping indices as shown in Table 4-9a, but the former had the smallest SI and the latter had a largest SI as shown in Figure 4-4. This is because the former had the highest mean residue density, while the latter had the lowest mean density.

Figure 4-5 indicates how different strip orientations result in different SIs. This means that strip sampling precision was affected by residue piece orientation although strip sampling is unbiased.

Figure 4-6 shows that narrowing strip width is more effective than reducing strip length for changing SI. Four strip widths (1, 2, 5, and 10 m) and three strip lengths (200, 100, and 50 m) were used in the simulations. A 10 m by 100 m strip has the same area compared with a 5 m by 200 m strip, but the latter had a lower SI as shown in Figure 4-6.

Figure 4-7 gives the results of using three sample units: measuring butts only on strips, measuring partial logs on strips and line transects. The strip width was fixed at 2 m, and line samples were obtained from the centre of the strips. Figure 4-7 tells us that measuring partial logs led to an approximate 5 percent reduction of SI compared with measuring butts only and a 1 percent reduction when compared with line transects.

Figure 4-8 indicates that mean residue densities estimated from parallel sample transects oriented in different directions were different. The figure also reveals that a stable estimate of residue density using line intersect methods required a large number of transects.

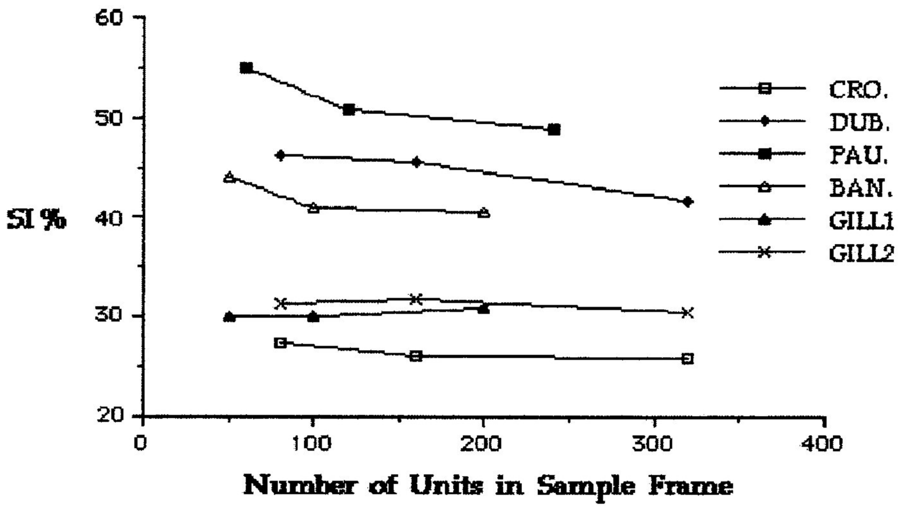


Figure 4-4. Sampling intensity (percent) required to reach 10 percent cv in relation to sample frame size and population when measuring butts only on 2 metre strips.

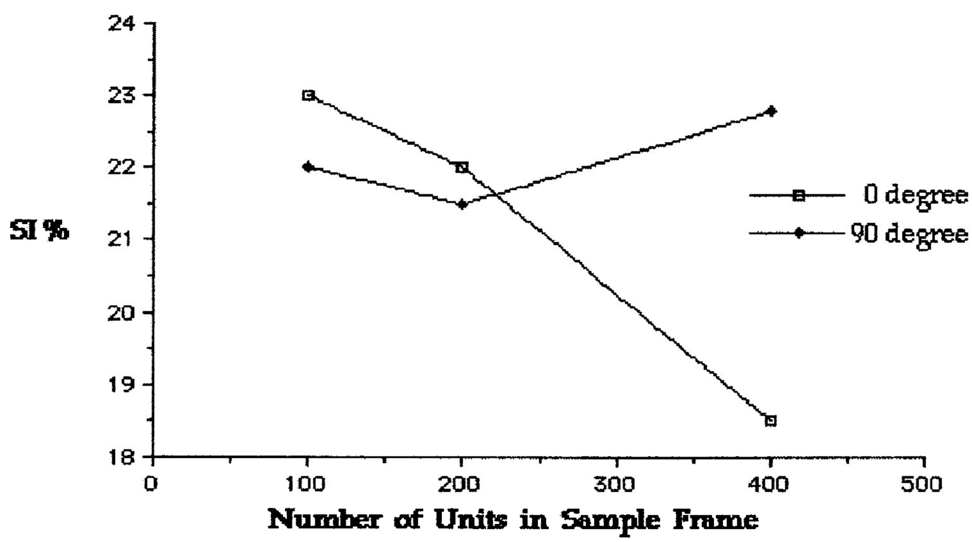


Figure 4-5. Sampling intensity (percent) required to reach 10 percent cv in relation to sample frame size and sample orientation when measuring butts only on 2 metre strips in the Crothers cutover.

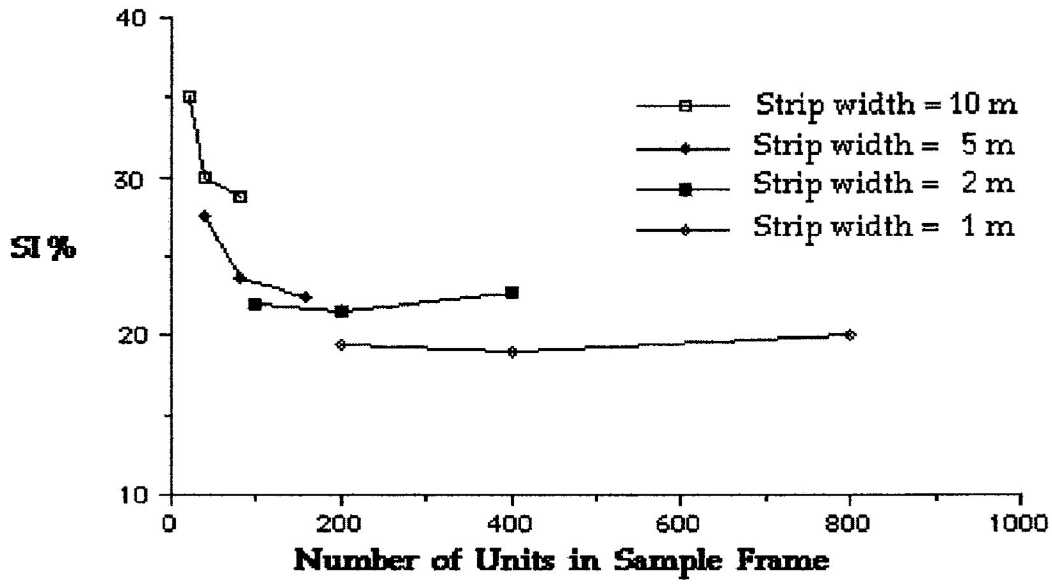


Figure 4-6. Sampling intensity (percent) required to reach 10 percent cv in relation to sample frame size and strip width for the Crothers cutover.

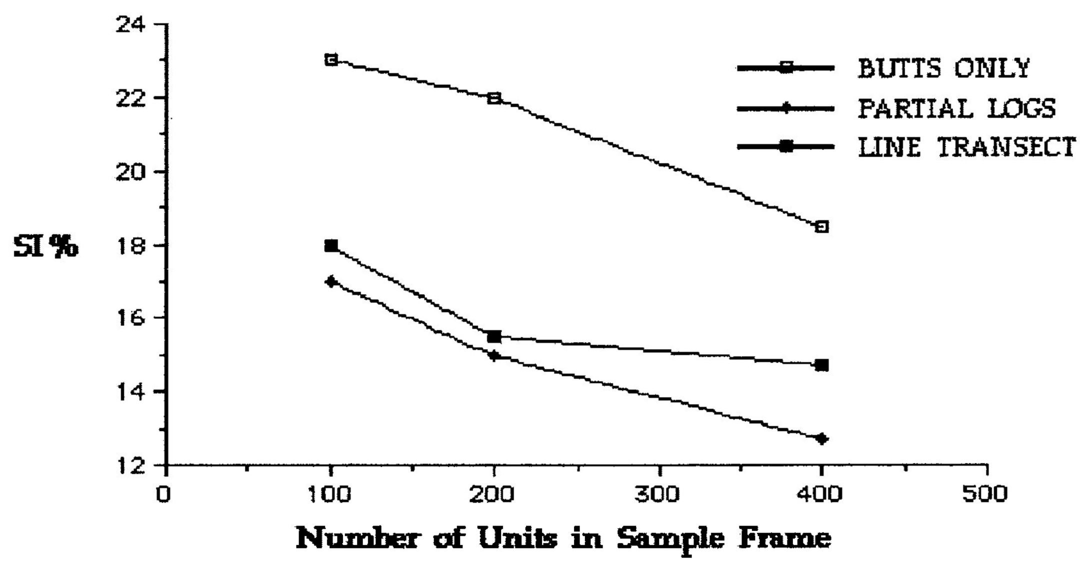


Figure 4-7. Sampling intensity (percent) required to reach 10 percent cv in relation to sample frame size and sampling methods for the Crothers cutover.

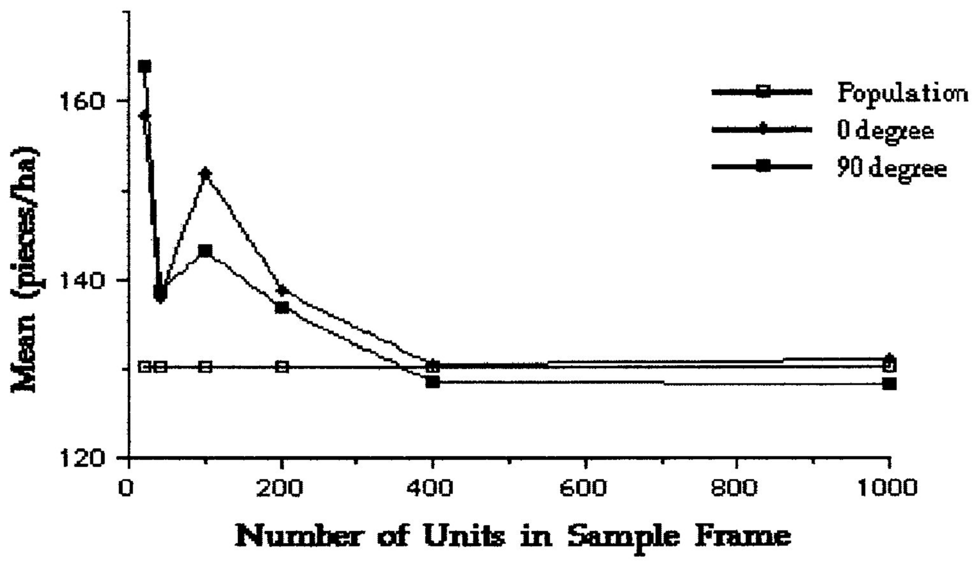


Figure 4-8. Line intersect sampling mean (pieces/ha) by sample orientation for the Crothers cutover.

SAMPLING IN INFINITE SAMPLE FRAMES

In this section, the criteria for comparison between sampling designs applied within individual populations are the variance of estimated mean density of residue and the coefficient of variation. When the mean densities between designs are approximately constant, the variance was used. When the mean densities varied, the coefficient of variation was preferred. A smaller variance or coefficient of variation due to a particular sample design, will result in less variation among the sample units within the frame. Such a design should lead to better precision of estimation and be preferable to the alternative, less precise designs. The simulations were conducted in original populations.

Single Transect

Given sample line lengths ranging from 10 to 30 m, 1000 randomly selected samples of 20 lines each were simulated. The results are summarized in Table 4-15. In the table, estimates of the population mean residue density varied when sample line length was changed. Fortunately, the differences between the estimates of density are small and their variances can be compared to determine which method is more precise. In Table 4-15, the values for both variances and coefficients of variation are inversely proportional to sample line length. This supports the results of Pickford and Hazard (1978).

Double Transect

Double transect sampling using two crossing lines, where the total sample line length was equal to that of a comparable single long transect, was also simulated 1000 times using SRS. The sample size was 20 transects. The results compared with the long single transect are given in Table 4-16. Table 4-16 reveals that although both single and double transects obtained unbiased estimators of the population size, the former consistently produced lower coefficients of variation.

Table 4-15. Results of sampling simulations using SRS of single transects in infinite populations.

Sample Size = 20
Repeated 1000 Times

Cutover	Transect Length	Mean Number of Pieces	Variance of Mean	Coefficient Variation
	m	pieces/ha	pieces/ha	%
	10	138.45	2734.079	1.89
CROTHERS	20	132.55	1401.663	1.41
	30	138.69	955.740	1.11
	10	59.18	670.532	2.19
DUBLIN	20	59.46	373.204	1.69
	30	61.51	255.269	1.30
	10	49.63	653.392	2.58
PAUDUSH	20	48.08	343.239	1.93
	30	48.07	222.605	1.55
	10	83.78	1834.648	2.56
BANNERMAN	20	89.87	1001.394	1.76
	30	80.82	610.132	1.53
	10	112.79	1996.043	1.98
GILL-1	20	106.60	1002.273	1.48
	30	104.28	658.840	1.23
	10	81.99	1814.781	2.60
GILL-2	20	79.71	820.406	1.80
	30	80.92	580.383	1.49

Triangular Transect

A triangular transect consisted of three lines whose total length equalled that of a comparable single long transect. The results of simulating the use of triangular transects compared with single lines are also listed in Table 4-16. The unbiased coefficients of variation of the triangular transect were larger than for both single and double transects (except Paudush cutover).

Circular Transect

A circle transect with a circumference of 30 m (radius defined as 4.7746483 m) was used as a sample unit. Simulation results of this design compared with the other transects are also listed as Table 4-16. Differences of unbiased estimates between the circular transect and the single transect are not obvious from the table. But the estimates of mean density using circular transect are more precise than the estimates using other combined short transects.

Table 4-16. Comparison of mean (pieces/ha) and variance of the mean resulting from simulated sampling by transect designs using SRS.

Sample Size = 20
Repeated 1000 Times

Cutover	Transect Type	Transect Length	Mean Number of Pieces	Variance of Mean	Coefficient Variation
		m	per ha	pieces/ha	%
	CIRCLE	1*30	129.99	865.170	1.13
CROTHERS	SINGLE	1*30	138.69	955.740	1.11
	DOUBLE	2*15	133.07	992.108	1.18
	TRIANGLE	3*10	134.90	1172.609	1.27
	CIRCLE	1*30	58.43	274.970	1.42
DUBLIN	SINGLE	1*30	61.51	255.269	1.30
	DOUBLE	2*15	57.27	275.710	1.45
	TRIANGLE	3*10	60.98	375.243	1.59
	CIRCLE	1*30	47.73	234.864	1.61
PAUDUSH	SINGLE	1*30	48.07	222.605	1.55
	DOUBLE	2*15	45.05	247.859	1.75
	TRIANGLE	3*10	48.75	270.044	1.69
	CIRCLE	1*30	85.72	671.481	1.51
BANNERMAN	SINGLE	1*30	80.82	610.132	1.53
	DOUBLE	2*15	84.49	706.077	1.57
	TRIANGLE	3*10	83.63	846.290	1.74
	CIRCLE	1*30	111.72	824.415	1.29
GILL-1	SINGLE	1*30	104.28	658.840	1.23
	DOUBLE	2*15	102.49	690.953	1.28
	TRIANGLE	3*10	102.37	729.569	1.32
	CIRCLE	1*30	82.01	563.303	1.45
GILL-2	SINGLE	1*30	80.92	580.383	1.49
	DOUBLE	2*15	83.11	670.814	1.56
	TRIANGLE	3*10	77.43	768.695	1.79

SIMULATED SAMPLING TRIAL

Sample Random Sampling

Computerized sampling simulation trials were conducted in six populations with their areas reduced so that they were all approximately the same area. Sampling simulations using transects of equal total length (30 m) were conducted to test various line sample designs as illustrated in Figures 4-9 (a-d). Figures 4-10 (a-f) show results of simulated sampling using butts only circular plots, partial logs circular plots and circular transects, by two sample unit sizes. All corresponding sample units for the three different methods were located at the same place. Figures 4-11 (a-c) illustrate estimated relative error of the estimates of mean density of residue for the three methods. Although the three figures present results for Crothers cutover, the results from the other cutovers showed the same trends. The points in the figures indicate relative precision of the sampling trials or relative error of estimated mean number of pieces per hectare. The curved line is a regression line which represents the tendency of the distribution of the relative precision or relative error of the mean. In order to help illustrate precision of the sampling trials, a dotted horizontal line was drawn in Figures 4-10 (a-f) and 4-11 (a-c) to show the boundary of the 25 percent relative value.

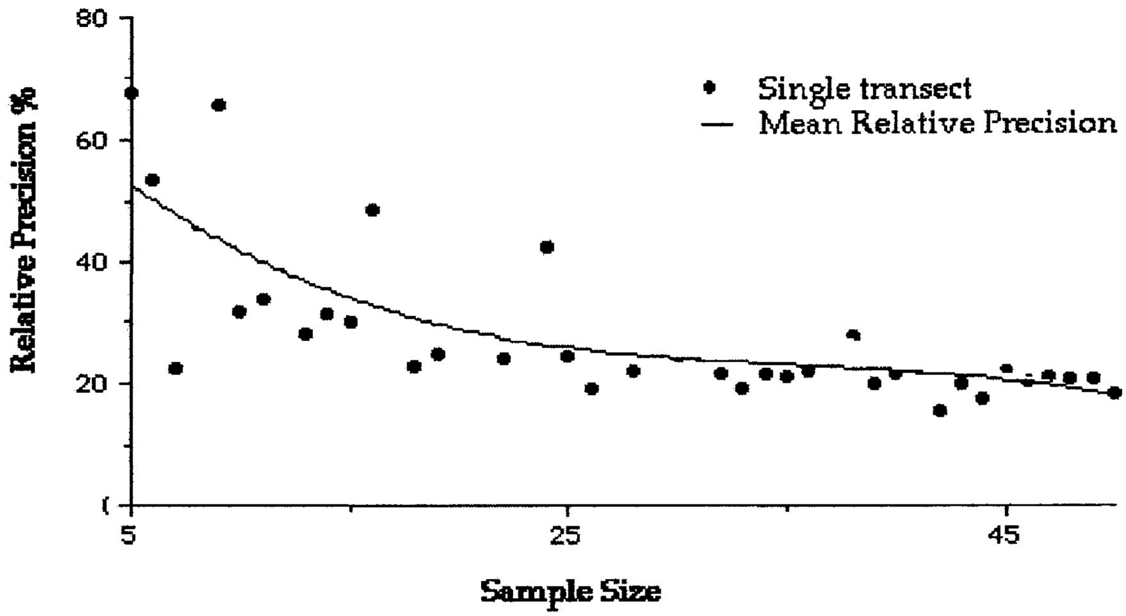


Figure 4-9a. Relative precision when estimating density of logging residue using single transect SRS sampling.

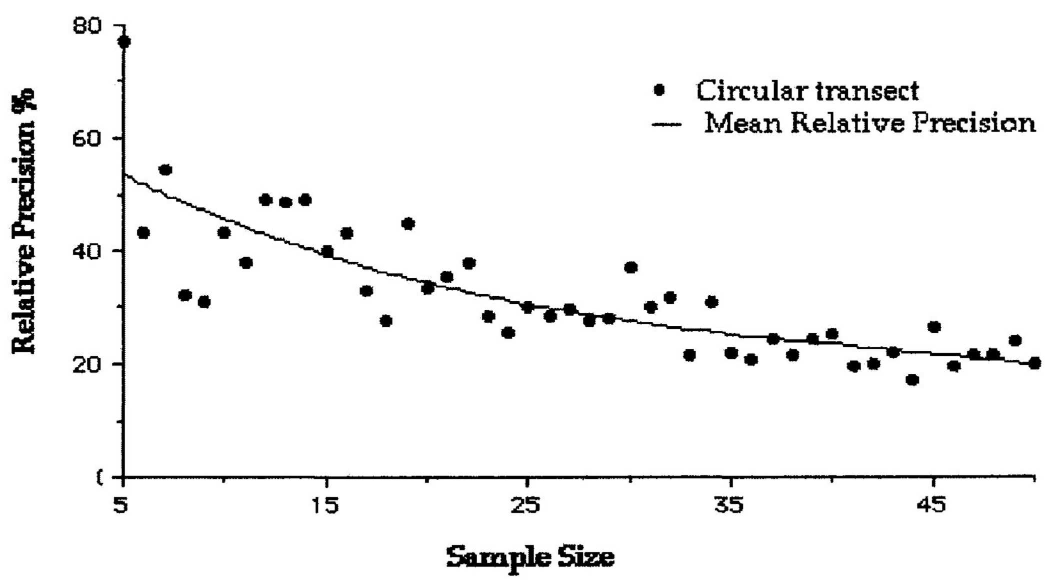


Figure 4-9b. Relative precision when estimating density of logging residue using circular transect SRS sampling.

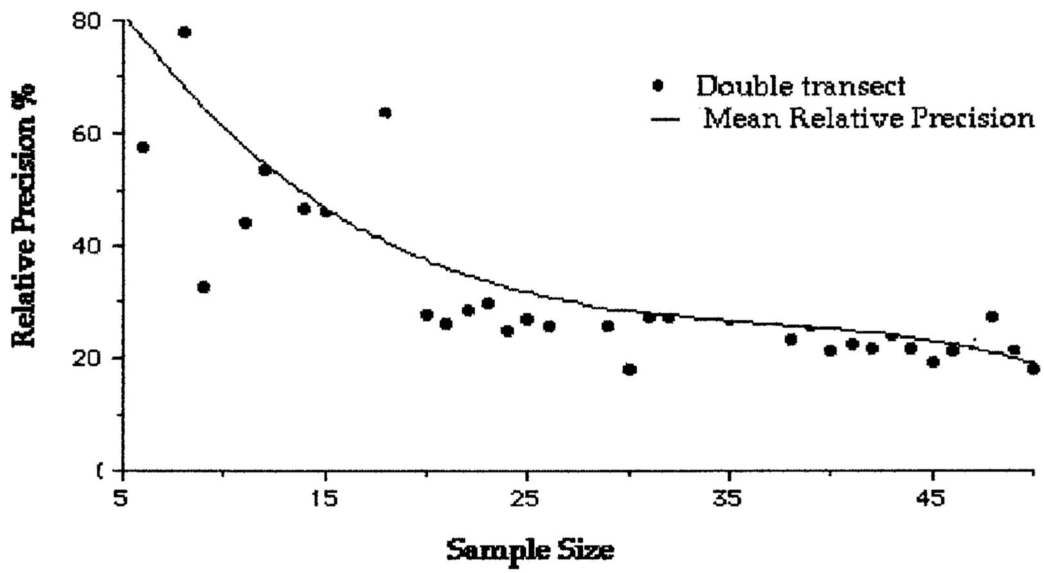


Figure 4-9c. Relative precision when estimating density of logging residue using double transect SRS sampling.

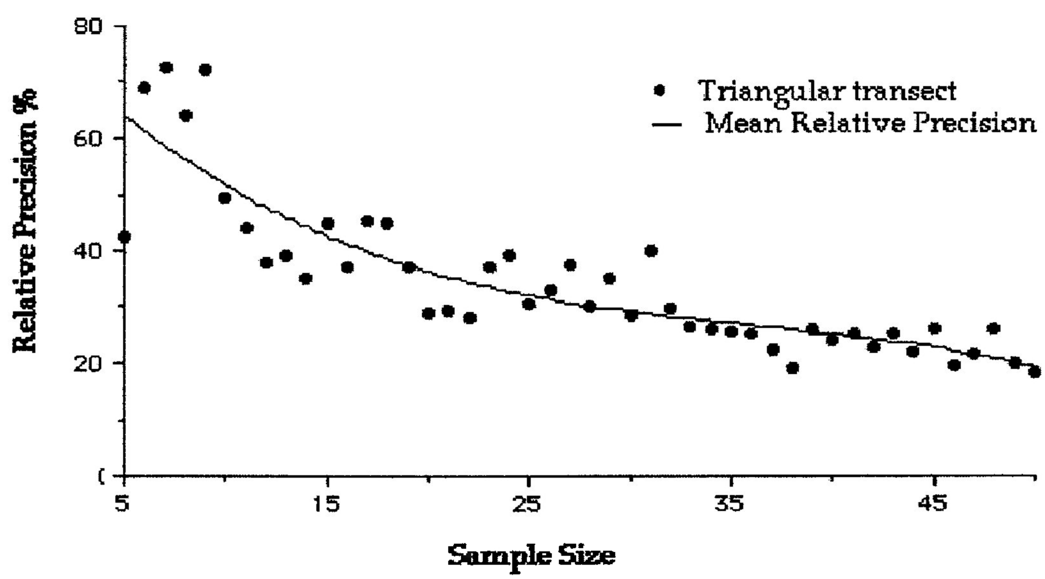


Figure 4-9d. Relative precision when estimating density of logging residue using triangular transect SRS sampling.

Figures 4-9a to 4-9d indicate that using one long straight line sample had higher sampling precision than using two or three combined shorter transects. Circular transects produced better estimates than two crossing or triangular line designs. These results support those from the simulations of finite and infinite sample frames. In addition, estimated sampling precision appears to be more stable when using the circular or triangular transects than when using the single and double transect designs and the sample sizes are small.

Figures 4-10 (a-b) and 4-10(c-d) give the results of changing plot size when sampling for the butts only and measuring partial logs, respectively. Figures 4-10 (e-f) show the effects of changing the circumference of circular transects. In these figures, sample sizes ranged from 5 to 50, and sampling trials were independent from each other.

When sample plot size was small (0.00785 ha), measuring partial logs on plots provided better estimates than measuring butts only (Figures 4-10a and 4-10c). When the plot size was larger (0.07069 ha), the two plot methods obtained similar precision (Figures 4-10b and 4-10d).

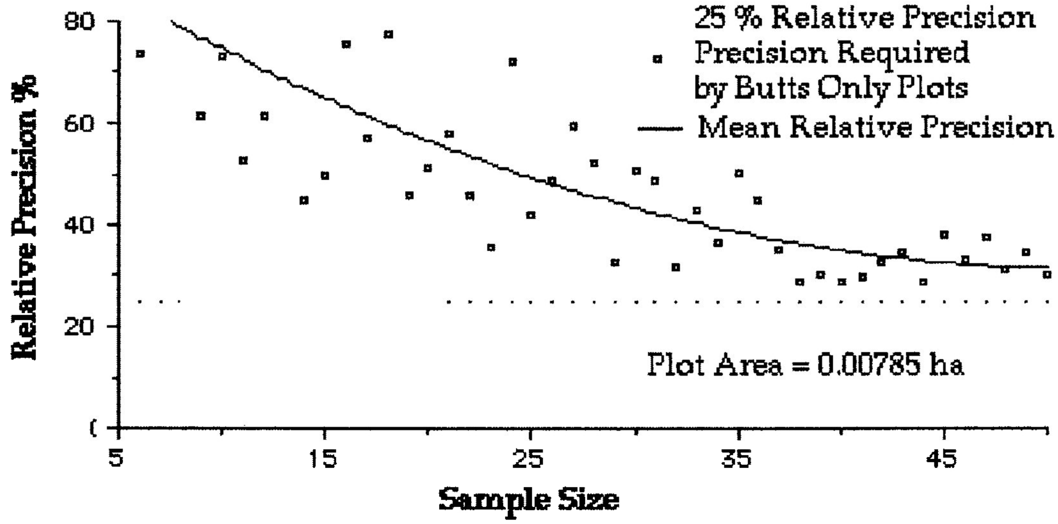


Figure 4-10a. Relative precision of estimating logging residue density in relation to SI when using 0.00785 ha circular plots and measuring butts.

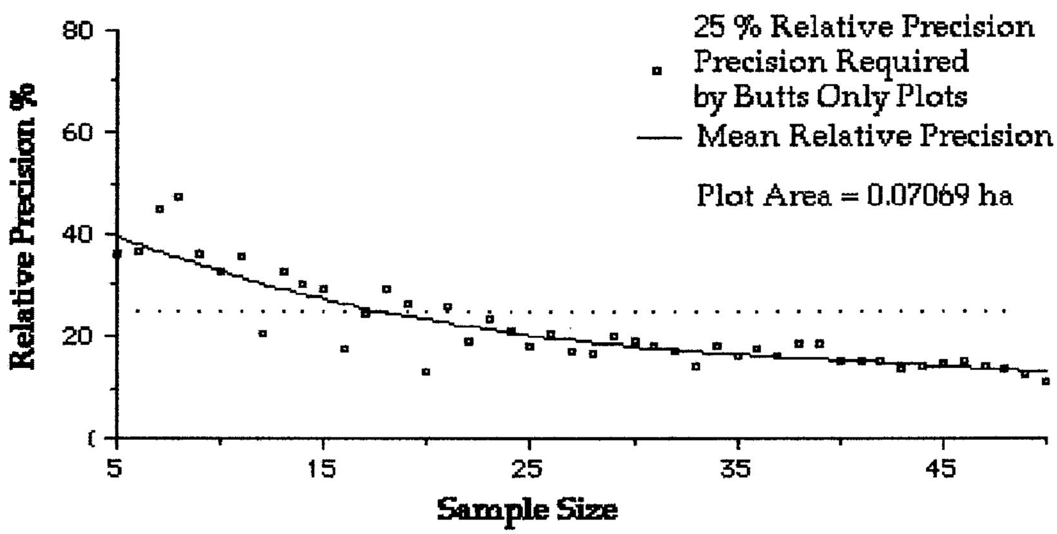


Figure 4-10b. Relative precision of estimating logging residue density in relation to SI when using 0.07069 ha circular plots and measuring butts.

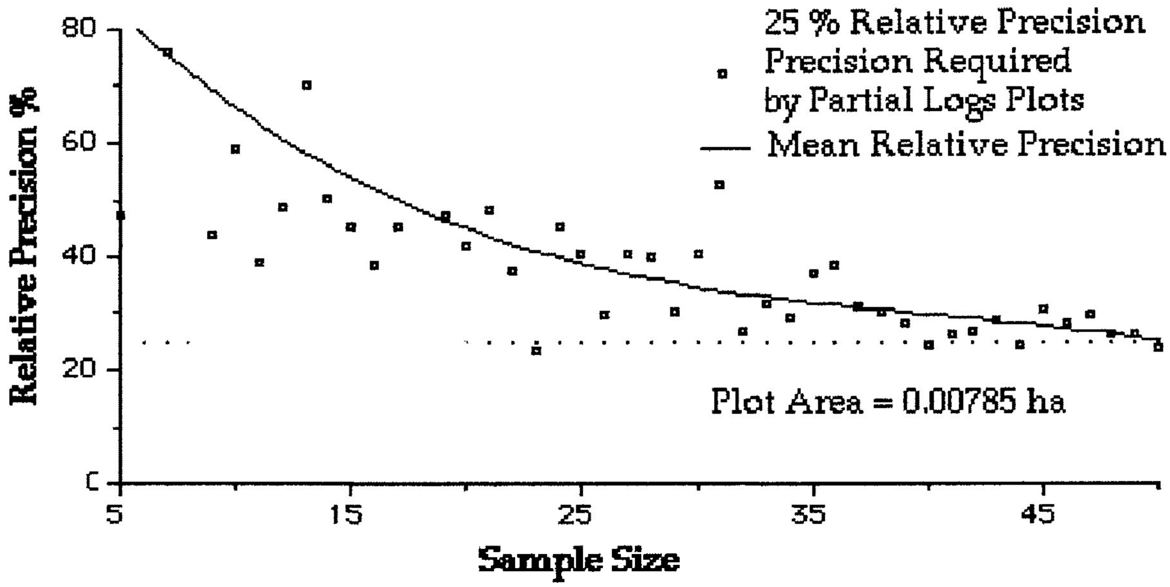


Figure 4-10c. Relative precision of estimating logging residue density in relation to SI when using 0.00785 ha circular plots and measuring partial logs.

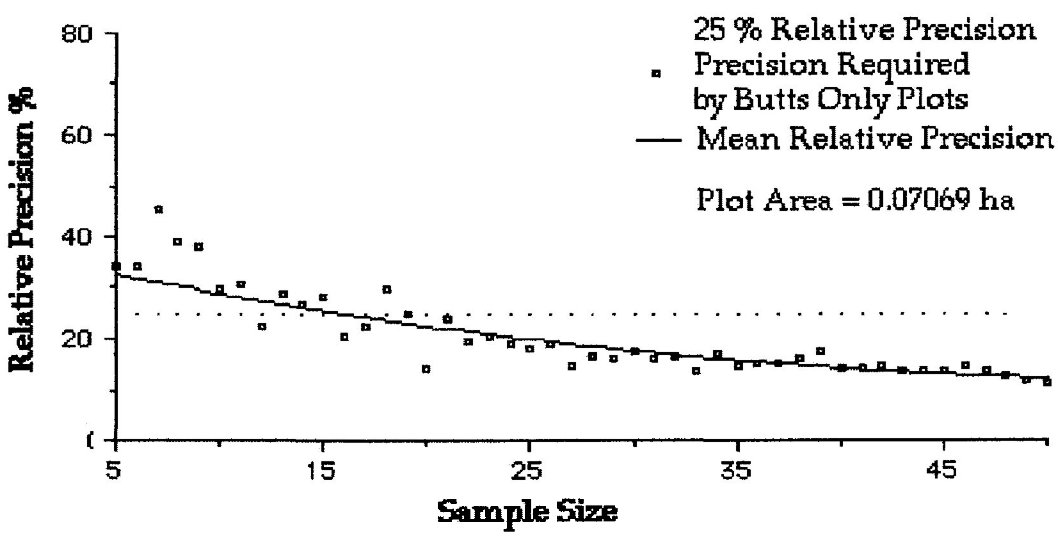


Figure 4-10d. Relative precision of estimating logging residue density in relation to SI when using 0.07069 ha circular plots and measuring partial logs.

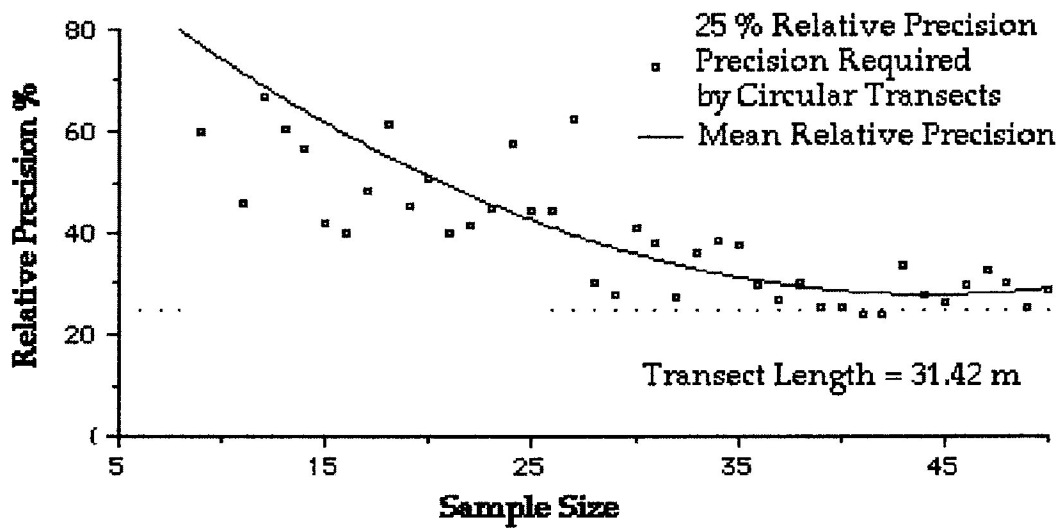


Figure 4-10e. Relative precision of estimating logging residue density in relation to SI when using 31.42 m circumference circular transects.

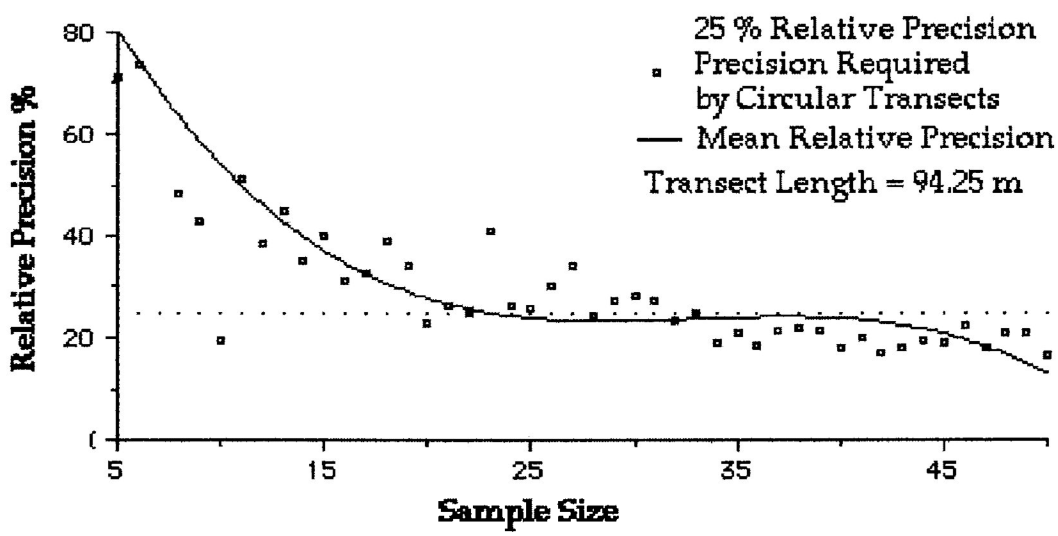


Figure 4-10f. Relative precision of estimating logging residue density in relation to SI when using 94.25 m circumference circular transects.

In addition, small plots appeared to be more efficient than large plots when sampling for residue density. For example, to achieve 25 percent sampling precision, measuring partial logs on small plots required approximately 50 plots for a total sampling area of 0.4 ha while measuring partial logs on large plots required approximately 15 plots for a total sampling area of 1.1 ha.

Using small circumference circular transects appeared to be more efficient than longer circumference circular transect as indicated in Figures 4-10e and 4-10f.

Figure 4-11 illustrates the relative errors of the estimates of mean density of logging residue. When the relative error of the mean density is compared with a required relative precision for estimating the mean density of residue, as shown in Figures 4-10b, 4-10d and 4-10f, we find that the values of relative precision are much higher than their corresponding relative errors. This indicates that the estimated confidence limits for the means are conservative and imply that there is still some potential for improving the sampling precision.

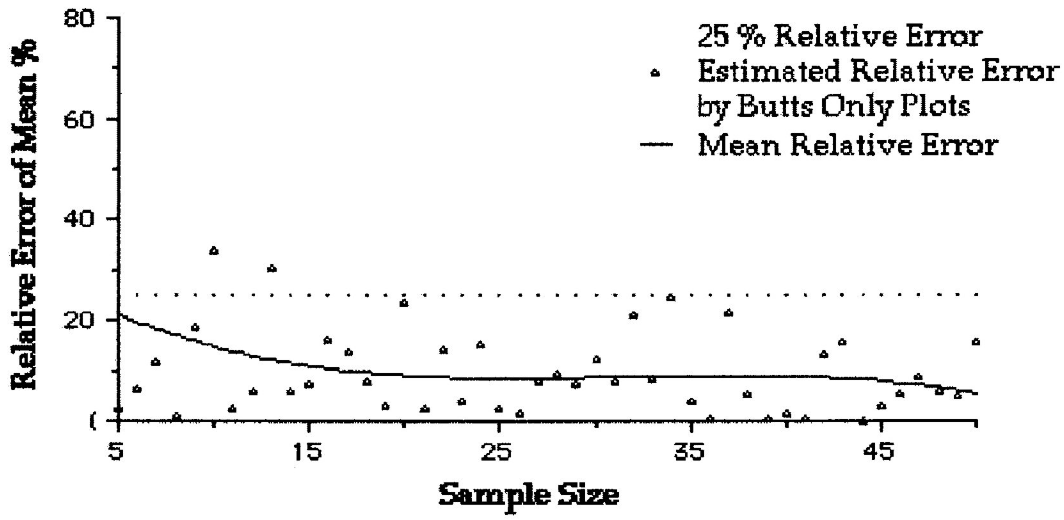


Figure 4-11a. Estimated relative error of mean residue density when measuring butts only on circular plots using SRS.

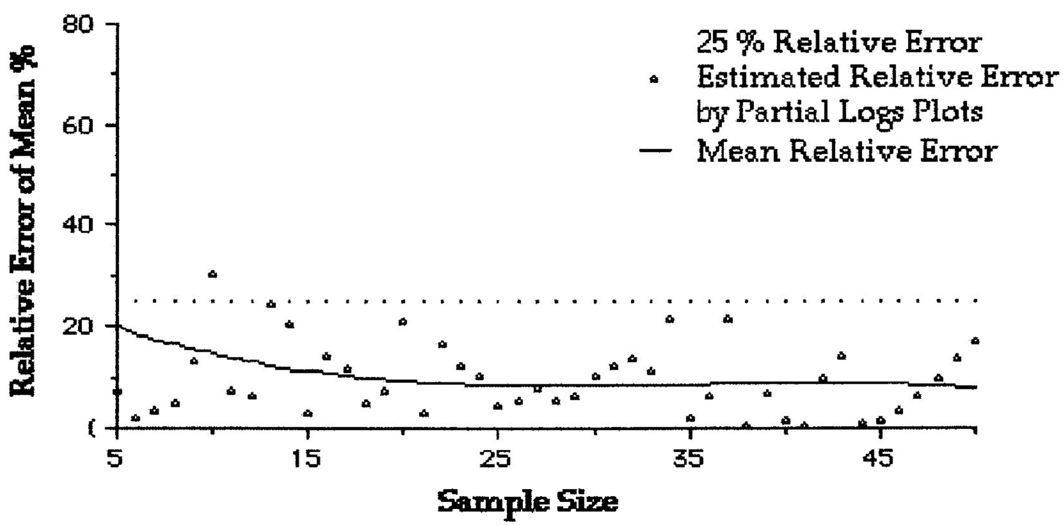


Figure 4-11b. Estimated relative error of mean residue density when measuring partial logs on circular plots using SRS.

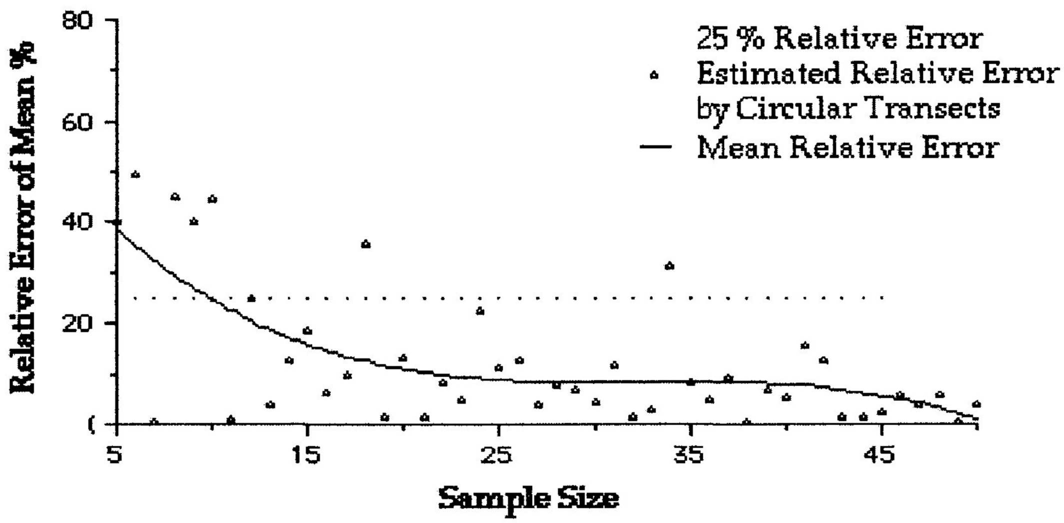


Figure 4-11c. Estimated relative error of mean residue density when using SRS circular transects.

Systematic Sampling versus SRS

Systematic sampling and SRS using four different transect designs were carried out for the six original cutovers. The sample size used in all sampling trials was 36 transects and each transect design had a total length of 30 m. All sampling trials were independent to each other. The results of relative error of sample mean for all trials are listed in Tables 4-17a to 4-17f.

In order to identify ranges of the relative error of sample means easily, the relative errors listed in Tables 4-17 (a-f) were sorted in ascending order for the 9 trials. The upper values of the ranges indicate that sampling accuracy is very low when using 36 30-metre transects for both systematic sampling and SRS. It is difficult to point out which sampling method using which transect design is better from the relative error ranges.

Table 4-17a. Relative error result for 9 independent trials from systematic sampling versus SRS using single, double, triangular and circular transects for the Crothers cutover.

Single		Double		Triangular		Circular	
SyS[a]	SRS	SyS	SRS	SyS	SRS	SyS	SRS
40.16	19.29	37.02	39.04	19.22	32.21	44.77	43.76
39.46	16.81	33.95	30.23	13.96	21.73	43.45	34.75
33.84	13.66	32.14	26.17	12.37	21.73	42.65	24.73
27.81	12.87	29.66	24.09	12.00	21.43	41.19	22.60
19.17	11.77	18.67	17.58	10.46	15.82	19.21	14.59
15.02	10.51	13.38	11.25	8.98	12.41	15.99	14.31
14.66	7.10	8.10	9.53	6.56	5.19	12.51	8.84
13.70	5.20	7.49	1.51	6.04	2.85	9.40	6.70
8.41	1.06	1.89	0.52	3.57	2.85	9.37	6.48

Table 4-17b. Relative error result for 9 independent trials from systematic sampling versus SRS using single, double, triangular and circular transects for the Dublin cutover.

Single		Double		Triangular		Circular	
SyS	SRS	SyS	SRS	SyS	SRS	SyS	SRS
30.58	31.19	28.23	47.14	53.14	21.97	29.53	48.25
12.97	19.23	27.77	34.87	49.20	21.61	26.25	17.28
8.76	15.94	13.32	19.44	31.66	12.44	25.21	17.28
6.99	13.51	9.42	18.92	30.15	12.17	22.45	13.00
5.38	11.59	6.56	16.09	18.09	11.62	20.65	12.55
5.07	11.27	5.80	11.09	10.84	5.92	16.05	12.55
2.52	10.23	4.44	3.24	10.76	5.19	13.61	6.14
1.15	7.89	2.49	2.19	5.47	2.39	10.36	2.24
0.32	7.20	1.01	0.85	2.22	1.85	7.62	0.32

a. SyS = Systematic sampling.

Table 4-17c. Relative error result for 9 independent trials from systematic sampling versus SRS using single, double, triangular and circular transects for the Paudush cutover.

Single		Double		Triangular		Circular	
SyS[a]	SRS	SyS	SRS	SyS	SRS	SyS	SRS
41.32	41.43	33.12	33.89	58.73	51.61	49.61	34.14
31.57	39.60	32.15	21.53	36.48	42.50	45.59	33.89
28.94	27.76	18.10	13.68	23.21	24.63	32.60	23.37
17.26	27.56	17.53	12.65	15.31	23.33	23.32	20.08
13.65	22.39	16.53	8.37	10.17	10.26	20.91	19.94
12.26	20.24	16.00	8.37	9.41	4.61	20.30	11.16
4.99	18.18	13.74	7.43	8.70	4.51	18.59	6.51
4.07	11.53	9.05	7.43	7.40	2.06	1.85	6.32
0.71	7.00	3.86	7.43	5.37	0.12	0.02	3.81

Table 4-17d. Relative error result for 9 independent trials from systematic sampling versus SRS using single, double, triangular and circular transects for the Bannerman cutover.

Single		Double		Triangular		Circular	
SyS	SRS	SyS	SRS	SyS	SRS	SyS	SRS
24.34	29.69	40.41	68.58	38.49	31.91	51.95	35.39
15.67	13.46	33.61	36.09	36.53	31.16	15.99	22.65
13.03	8.30	27.99	27.27	28.83	30.69	11.06	21.42
10.30	7.29	17.94	23.75	26.3	26.06	10.35	19.07
9.66	5.37	15.69	20.45	25.45	20.23	8.83	17.22
8.27	3.14	14.50	5.91	14.25	7.90	4.74	12.09
5.13	2.88	9.46	4.43	12.62	2.70	4.38	9.32
2.63	1.23	2.36	4.36	12.07	1.30	3.63	8.68
1.40	0.96	1.71	1.41	5.33	0.35	1.06	2.32

a. SyS = Systematic sampling.

Table 4-17e. Relative error result for 9 independent trials from systematic sampling versus SRS using single, double, triangular and circular transects for the Gill-1 cutover.

Single		Double		Triangular		Circular	
SyS[a]	SRS	SyS	SRS	SyS	SRS	SyS	SRS
32.43	30.26	36.58	23.44	52.45	69.49	32.29	24.73
30.33	29.51	28.14	17.30	48.29	24.19	30.38	21.55
24.07	27.58	27.63	17.30	43.56	23.78	29.80	20.83
14.46	23.24	22.26	15.49	40.95	18.97	27.11	20.56
9.96	12.65	16.29	13.75	21.96	15.30	19.84	16.74
9.07	6.04	10.50	13.75	17.32	5.40	18.73	14.59
8.55	5.44	10.15	6.96	13.10	2.12	6.90	12.68
2.24	4.56	5.86	6.22	8.69	0.54	3.00	11.12
0.60	2.23	5.24	5.36	5.06	0.22	0.82	0.85

Table 4-17f. Relative error result for 9 independent trials from systematic sampling versus SRS using single, double, triangular and circular transects for the Gill-2 cutover.

Single		Double		Triangular		Circular	
SyS	SRS	SyS	SRS	SyS	SRS	SyS	SRS
38.87	43.25	56.78	51.77	58.43	47.75	29.20	38.88
27.86	43.25	56.03	15.83	47.12	24.68	26.53	30.76
25.26	26.27	43.26	14.67	44.24	23.96	24.64	29.72
11.71	26.26	36.45	13.89	13.66	18.72	20.33	11.16
11.68	25.00	20.14	12.79	12.64	15.02	7.01	10.42
10.58	15.55	11.71	5.11	5.09	14.20	6.24	9.79
8.12	10.56	2.45	3.86	3.95	14.07	4.69	7.80
6.51	2.65	1.24	2.49	1.96	12.64	2.71	3.42
5.43	2.65	0.28	2.14	0.39	5.16	1.50	2.14

a. SyS = Systematic sampling.

<u>Stratified Sampling</u>

Stratified RS measuring butts only and partial logs on plots was conducted. Stratification was based on residue (occupied) and void (empty) plots. The results are listed in Tables 4-18a and 4-18b, respectively.

When sampling intensity required in the residue stratum (Table 4-18a) is compared with that required for the whole sample frame (Table 4-13a), a drastic reduction of sampling intensity occurred when measuring butts only. For example, in the Crothers cutover, when the sample plot area was 25 m^2, a SI of 6.4 percent was required for stratified sampling (see Table 4-18a) to meet the 20 percent relative error requirement. In this same situation, non-stratified sampling required a SI of 40.5 percent (see Table 4-13a).

Comparing Table 4-18a with Table 4-18b, it is obvious that measuring butts only required lower sampling intensities than measuring partial logs in stratified sampling with known strata weights. This is especially true for low density residue populations. In the Paudush cutover, the butts only system required a SI of 9.1 percent and the partial logs measurement system required a SI of 28.9 percent. This was because all residue samples on the butts only plots had similar residue densities. This was not the case when measuring partial logs on this area.

Table 4-18a. Sampling intensity required in residue stratum when measuring butts only on plots for the reduced regular shaped cutover areas and measuring only the dominant species.

Cutover	Sample Frame Mean	Plot Area	Number of Sample Units		SI
	pieces/ha	m^2	Sample Frame	With Residue	%
		25	1024	140	6.4
CROTHERS	61.72	100	256	108	18.5
		25	1024	58	12.1
DUBLIN	24.61	100	256	55	20.0
		25	1056	44	9.1
PAUDUSH	17.42	100	264	39	23.1
		25	1040	180	7.8
BANNERMAN	84.23	100	260	135	19.3
		25	1040	181	11.0
GILL-1	86.15	100	260	129	26.4
		25	1024	180	8.9
GILL-2	81.64	100	256	144	13.9

Table 4-18b. Sampling intensity required in residue stratum when measuring partial logs on plots for the reduced regular shaped cutover areas and measuring only the dominant species.

Cutover	Sample Frame Mean	Plot Area	Number of Sample Units		SI
	pieces/ha	m^2	Sample Frame	With Residue	%
	60.91	25	1024	280	15.0
CROTHERS	60.91	100	256	156	24.4
	24.17	25	1024	123	28.5
DUBLIN	24.17	100	256	78	34.6
	16.25	25	1056	90	28.9
PAUDUSH	16.25	100	264	65	36.9
	81.62	25	1040	301	15.6
BANNERMAN	81.37	100	260	163	27.6
	84.34	25	1040	333	15.6
GILL-1	84.26	100	260	166	25.9
	80.30	25	1024	315	14.4
GILL-2	80.30	100	256	174	19.5

Poststratification

Since the residue sample units are unknown in practice, a poststratified method had to be used to determine the proportion of sampled areas occupied by residue. Several trials using RS with poststratification were conducted in both finite and infinite sample frames. The sampling intensity was arbitrarily set at 20 percent. Ten independent repeated trials were made in each sample frame.

For the finite sample frames, the butts only and partial logs measurement systems were tested for 1, 2 and 5 m wide strips. The results are listed in Appendix B.

Tables 4-19 (a-b) present results from 1 m wide strip sampling trials for the Crothers cutover. Table 4-19a revealed that less than 1.5 percent differences in estimating precision occurred when SRS and poststratified RS are applied using partial logs measurement on 1 m wide strips. This was because no, or only few void strips existed in this sample frame. Measuring butts only on 1 m wide strips using poststratification did lead to an improvement (greater than 3.5 percent) in precision of estimation of residue as shown in Table 4-19b. This was because of the reduction in the coefficient of variation of the estimated mean for residue in the occupied stratum. Comparing both nonstratified and poststratified situations in Tables 4-19a and 4-19b, the butts only measurement system produced poorer estimates of mean density of residue. The results from 1 m wide strip sampling for other cutovers agreed with these results.

Table 4-19a. Partial logs stratified strip sampling in Crothers cutover.

Trial	Sample Frame		Residue Sample Frame	
	Mean pieces/ha	Coefficient of Variation	Mean pieces/ha	Coefficient of Variation
1	66.81	0.096	66.81	0.096
2	53.19	0.104	58.64	0.090
3	54.70	0.090	56.47	0.086
4	54.70	0.090	56.47	0.086
5	67.71	0.086	67.71	0.086
6	62.70	0.098	64.72	0.094
7	53.80	0.118	55.54	0.114
8	62.43	0.092	62.43	0.092
9	50.02	0.096	51.63	0.092
10	65.58	0.080	65.58	0.080

Table 4-19b. Butts only stratified strip sampling in Crothers cutover.

Trial	Sample Frame		Residue Sample Frame	
	Mean pieces/ha	Coefficient of Variation	Mean pieces/ha	Coefficient of Variation
1	82.03	0.138	109.38	0.103
2	48.83	0.191	86.81	0.129
3	62.50	0.139	90.91	0.088
4	62.50	0.188	111.11	0.126
5	74.22	0.174	125.00	0.113
6	52.73	0.151	88.82	0.073
7	56.64	0.156	90.63	0.095
8	62.50	0.188	111.11	0.126
9	68.36	0.129	91.15	0.090
10	68.36	0.157	99.43	0.115

There were slight differences in estimating precision when SRS and poststratified RS are applied using wider strips, because few void strips existed.

For the infinite sample frames, measuring partial logs on circular plots, butts only on circular plots and circular transects using RS with poststratification were tested. The sampling intensity remained set at 20 percent. The plot radius ranged from 2 to 5 m. Repeated sampling for all three designs was conducted for 10 trials with replacement. Results are listed in Appendix C.

The results of these trials indicate that using the butts only measurement system was usually the least accurate way to estimate the population mean density, and often exceeded the 20 percent allowable error guideline. This is demonstrated in Table 4-20a which gives the results of using 2 m radius plots in the Crothers cutover. In order to compare the results easily, relative values were calculated and listed in Table 4-20b for the Crothers cutover, and illustrated in Figures 4-12a to 4-12f for all cutovers.

Table 4-20a. Results of using 2 m radius plots and circular transects for poststratified random sampling in Crothers cutover.

Trial	Method	Sample Frame		Residual Stratum Sample Frame	
		Mean pieces/ha	Variance of Mean	Mean pieces/ha	Variance of Mean
1	P[a]	60.16	71.679	354.88	986.321
	C	56.59	52.812	333.80	499.116
	B	60.61	132.747	881.04	2243.686
2	P	64.23	70.549	318.78	753.332
	C	62.71	50.456	311.24	300.276
	B	74.30	155.024	863.98	1459.609
3	P	58.27	61.824	334.01	739.804
	C	51.36	43.986	302.94	428.296
	B	46.93	86.552	795.77	0.000
4	P	51.73	45.923	288.43	495.600
	C	59.61	47.083	332.37	221.153
	B	64.52	131.541	847.12	1273.984
5	P	59.16	73.545	354.06	1108.966
	C	56.19	52.898	341.35	501.833
	B	70.39	148.753	868.12	1635.479
6	P	61.11	77.041	355.29	1120.904
	C	60.19	59.341	349.99	560.221
	B	54.75	115.251	856.99	1798.602
7	P	57.25	56.749	319.19	622.874
	C	58.98	48.745	328.83	300.060
	B	70.39	141.088	842.59	1062.401
8	P	70.37	83.108	367.17	871.245
	C	66.27	58.539	350.31	343.752
	B	66.48	134.743	845.51	1196.932
9	P	58.60	56.985	331.26	569.905
	C	60.53	55.978	342.15	452.324
	B	52.79	104.273	826.38	936.771
10	P	57.75	68.902	335.76	1004.395
	C	54.59	49.342	332.02	471.285
	B	64.52	131.541	847.12	1273.982

a. P = Partial logs; C = circular line; B = Butts only.

Table 4-20b. Relative results of using 2 m radius plots and circular transects for poststratified random sampling in Crothers cutover.

Trial	Method	Sample Frame		Residual Stratum Sample Frame	
		Mean error	Coefficient of Variation	Mean pieces/ha	Coefficient of Variation
1	P[a]	-0.025	0.141	354.88	0.088
	C	-0.083	0.128	333.80	0.067
	B	-0.018	0.190	881.04	0.054
2	P	0.041	0.131	318.78	0.086
	C	0.016	0.113	311.24	0.056
	B	0.204	0.168	863.98	0.044
3	P	-0.056	0.135	334.01	0.081
	C	-0.168	0.129	302.94	0.068
	B	-0.240	0.198	795.77	0.000
4	P	-0.162	0.131	288.43	0.077
	C	-0.034	0.115	332.37	0.045
	B	0.045	0.178	847.12	0.042
5	P	-0.041	0.145	354.06	0.084
	C	-0.090	0.129	341.35	0.066
	B	0.140	0.173	868.12	0.047
6	P	-0.010	0.144	355.29	0.094
	C	-0.025	0.128	349.99	0.068
	B	-0.113	0.196	856.99	0.049
7	P	-0.072	0.132	319.19	0.078
	C	-0.044	0.118	328.83	0.053
	B	-0.140	0.169	842.59	0.039
8	P	0.140	0.130	367.17	0.080
	C	0.074	0.115	350.31	0.053
	B	0.077	0.175	845.51	0.041
9	P	-0.051	0.129	331.26	0.072
	C	-0.019	0.124	342.15	0.062
	B	-0.145	0.193	826.38	0.037
10	P	-0.064	0.144	335.76	0.094
	C	-0.116	0.129	332.02	0.065
	B	0.045	0.178	847.12	0.042

a. P = Partial logs; C = circular line; B = Butts only.

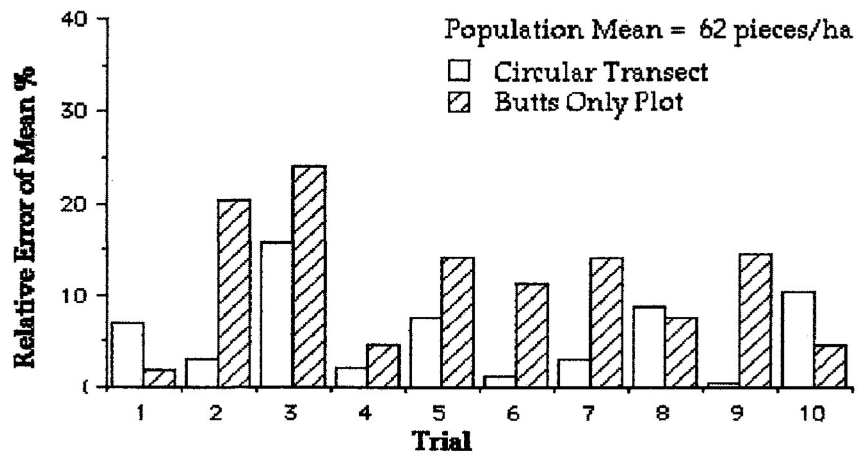


Figure 4-12a. Relative errors of mean density of residue using poststratification sampling or SRS with circular transects and circular plots measuring butts only in Crothers cutover.

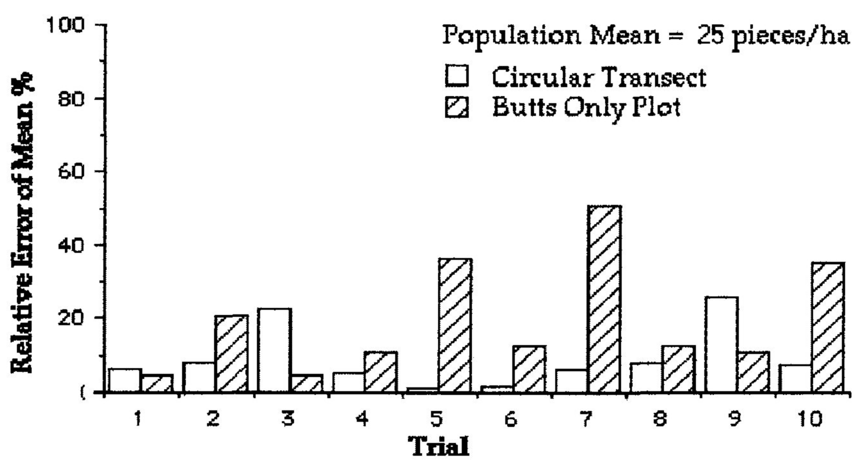


Figure 4-12b. Relative errors of mean density of residue using poststratification sampling or SRS with circular transects and circular plots measuring butts only in Dublin cutover.

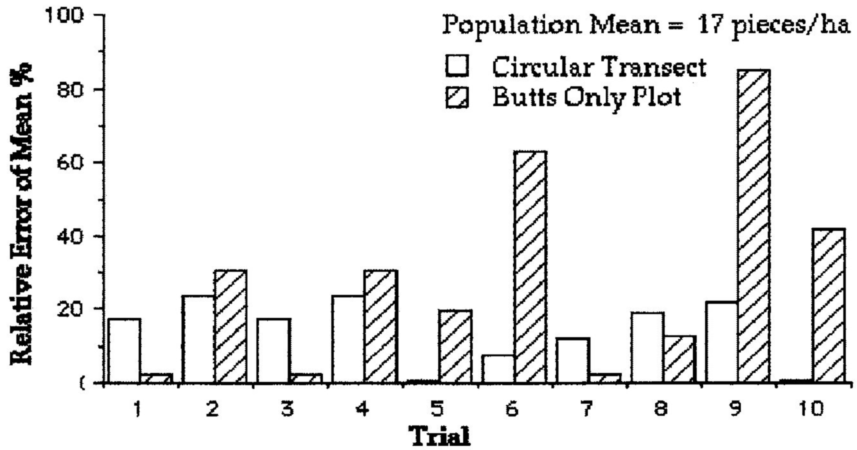


Figure 4-12c. Relative errors of mean density of residue using poststratification sampling or SRS with circular transects and circular plots measuring butts only in Paudush cutover.

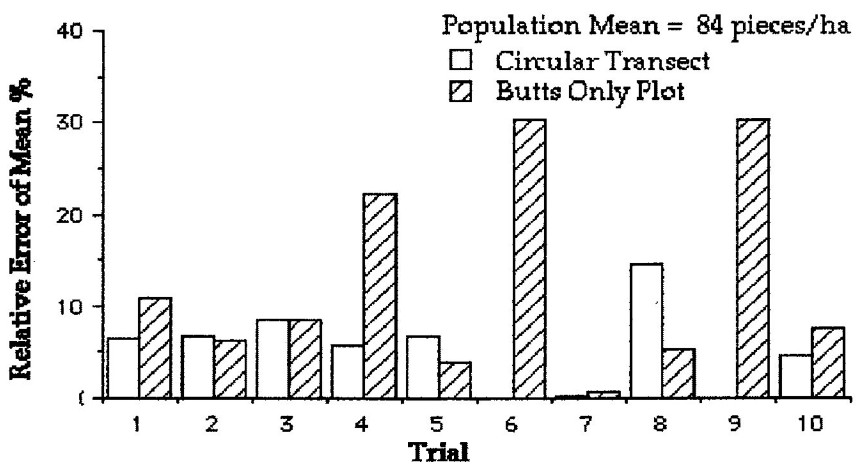


Figure 4-12d. Relative errors of mean density of residue using poststratification sampling or SRS with circular transects and circular plots measuring butts only in Bannerman cutover.

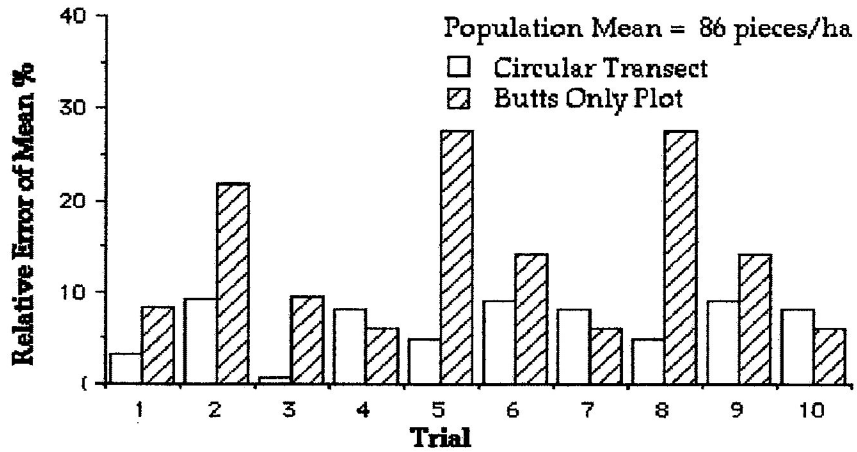


Figure 4-12e. Relative errors of mean density of residue using poststratification sampling or SRS with circular transects and circular plots measuring butts only in Gill-1 cutover.

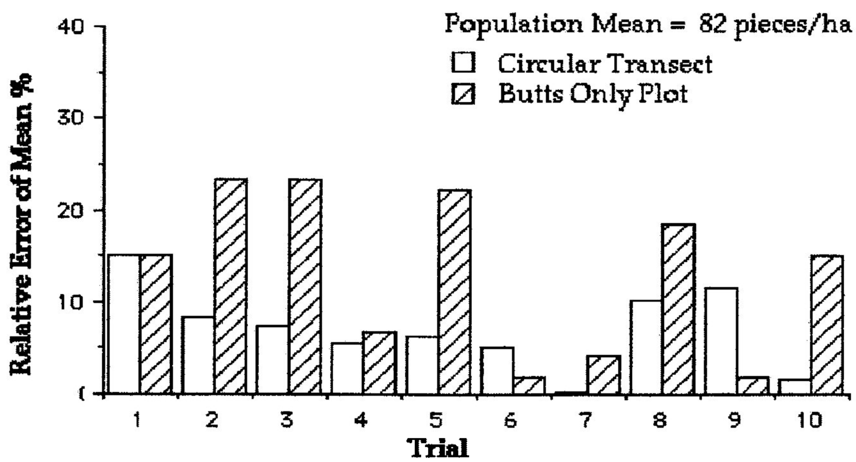


Figure 4-12f. Relative errors of mean density of residue using poststratification sampling or SRS with circular transects and circular plots measuring butts only in Gill-2 cutover.

In Table 4-20b, both SRS and stratified RS estimates of residue density were calculated for the purpose of comparison. The mean density is the same for SRS and RS using poststratification within the same sample frame. With SRS, the circular transect sampling produced the minimum coefficient of variation in each trial and measuring partial logs on plots always produced lower coefficients of variation than measuring butts only. But, in the poststratified RS, the butts only measurement produced lower coefficients of variation than partial logs measurement. The zero coefficients of variation in the third trial using butts only measurements can be explained by all selected sample plots having the same number of pieces of residue.

The relative errors between sampling means and sample frame means are presented in Figures 4-12 (a-f). The figures illustrate the results of ten SRS or poststratified RS trials using butts only plots and circular transects in six cutovers. Although estimates of measuring butts only on plots show lower relative error in some trials, it is obvious that the estimates of using circular transects had lower relative errors in most trials. The results of measuring partial logs on plots are not illustrated in the figures, but the results were very close to those of the circular transect.

CHAPTER FIVE: DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

DISCUSSION

The purpose of the sampling simulation performed in this study was to find the best or most suitable sample designs for merchantable logging residue sampling in northeastern Ontario. Results of the simulation revealed major problems in residue sampling.

Spatial Pattern Analysis

Although the data from the six cutovers varied by logging method, cutting season and major residue species, the spatial patterns of residue on the cutovers were similar. The logging residue was left on the ground through mistakes, careless logging, or because it was uneconomic to recover individual or small clusters of logs. Many authors assumed these factors lead to random spatial distribution patterns of logging residue or that spatial distribution patterns are associated with harvesting method. Such was not the case in this study, as all cutovers mapped showed clustered patterns of residue distribution. The degree of clustering of the pulpwood and log sized residue varied but could not be associated with cutover types.

For detecting the spatial patterns of log-size residue, quadrat-variance methods can be used for any population. Since different cutovers have different densities of residue, the quantity will affect variation among plots. A sample frame with low density usually has a small absolute value of variance. However, these sample frames may show high levels of relative variance of density. Therefore, for comparing residue spatial patterns among different populations, the modified quadrat-variance method using coefficient of variation of mean density may be more applicable.

SRS Versus PPS in Unequal Strip Ratio Estimation

In the Monte Carlo simulation trials, estimates of randomly selected samples using PPS sampling resulted in constant low values of variance of mean density compared with the calculated variances of this mean for the sample frames (Table 4-10). This can be explained as follows. In simulations using the PPS sample rules, each run only selected a few sample strips with higher probabilities of selection. After repeating the process many times, the estimated variance should represent the variance of the sample strips with the higher selection probabilities. The variance of the mean for a few sample strips, of course, is not equal to the variance of the mean of all sample strips because the latter is calculated using equal selection weight for every strip.

According to Cochran (1977), "the ratio estimate has a bias of order 1/n. Since the s.e. of the estimate is of order $1/\sqrt{n}$, the quantity (bias/s.e.) is also of order $1/\sqrt{n}$ and becomes negligible as n becomes large." Therefore, when using simulation, which is a repeatable process, to estimate the mean of a sample frame and the variance of the mean, the SRS sample rule should be used. But, for unrepeatable sampling, such as surveys using small but adequate sample size (i.e. $1/\sqrt{n} \approx 0$), PPS sample rules using ratio estimation should be used.

Plot Size and Plot Shape

Since a cutover is a continuous habitat, the population units have to be divided arbitrarily into sample units. The shape and the size of the sample units will affect the variance of the mean estimated from the sample frame although the population mean remains constant. Usually the mean derived from a sample frame is expected to equal the population mean. This is true for an unbiased sampling design.

Sampling intensity required for estimating residue volume or residue density is often inversely proportional to sample plot size. This was demonstrated in SRS measuring butts only on strips (Figure 4-4) and measuring butts only on plots (Tables 4-12a and 4-13a). But, for spatially clustered populations, the use of small sample units was not always successful in this study for reducing the SI. For example, in the Table 4-12a, sampling in the Gill-2 cutover gave the opposite result: the smaller sample plot, the larger the SI required. Since variation among sample units depends on numbers of population elements in each sample unit, a population can be divided into sample units which will result in the least variation by using an optimum size of sample unit. However, it is not practical to improve the estimation precision by changing the sample unit size, since we cannot know what size of plot which would divide a population into the most homogeneous sample units prior to sampling.

Figure 4-6 revealed that narrowing strip width was more effective than reducing strip length for improving sampling precision. This can be explained as follows. Suppose that cluster sampling is conducted in a sample frame consisting of small square plot sample units. Two kinds of clusters, strips and square or circular plots, can be chosen for sampling. Since adjacent small sample units are expected to have strong correlation, the compact group includes more homogeneous small sample units than does a design which separates the units spatially, such as strips. Because the variation among the individual plots within a sample frame is fixed, the larger the variation within a cluster of sample units, the lower will be the expected variation between the clusters. For example, when sampling in a population with a very clustered distribution and with the normal density expected with logging residue, plots located in areas of low density, may be expected to be void. Alternately, plots located in areas of high density would contain large quantities of residue. However, a strip sample may cover a great range of residue spatial patterns so that on average, a moderate amount of residue density may result. This leads to lower variance of the estimated mean density when sampling with strip clusters.

From the practical point of view, very long strips with random orientation are difficult to carry out. Precision of parallel strip sampling could be affected by residue piece orientation. A strip sample with the same orientation as most residue pieces will sample fewer pieces than a strip sample running perpendicular to the orientation of most residue pieces. This is a limitation of strip sampling.

Line Sample Designs

Considering the excessive walking time necessary when using single long transect sample units and the piece orientation problem when using parallel transects, three other line sample designs were tested. When compared with a single randomly oriented transect, using two shorter crossing transects with a combined length equal to the single transect lost little sampling precision. Using three much shorter lines arranged in a triangle with the total length of a single transect resulted in slightly lower precision. Circular transects resulted in about the same sampling precision as the single line transect (Table 4-15). This can be explained as follows. The single straight transect takes advantage of long narrow plots to cover a great range of residue spatial patterns in one direction. The circular transect covers a smaller range of residue spatial patterns than the single transect in one direction, but takes advantage of sampling other directions. Also, because a circumference is the shortest line that contains the largest area, sampling correlation between segments of the circumference will be expected to be lower than for segments of triangular or square transects.

Systematic Sampling

Systematic sampling obtained similar results to SRS when using random oriented transects. This agrees with the conclusion of Hazard and Pickford (1986). However, sampling accuracy was not satisfactory for the purpose of this study when using only 36, 30 m sample transects.

Poststratified sampling

The results of the strip sampling trials revealed that poststratified RS when measuring butts only on narrow strips, did improve sampling precision (Table 4-19b), while poststratified RS when measuring partial logs on the same strips, did not achieve any obvious improvement (Table 4-19a) over SRS. In plot sampling, stratified RS when measuring butts only, required lower sampling intensities (Tables 4-18) and obtained lower coefficients of variation in poststratified residue stratum (Table 4-20b). Measuring partial logs achieved better estimates of the population mean residue density (Table 4-20a). In order to further discuss these results, Tables 5-1 and 5-2 list proportions of residue samples and void samples from ten SRS trials for strip and plot sampling, respectively.

Table 5-1 describes numbers of void sample strips found in samples of 32 units using butts only and partial logs enumeration. It is easy to see that measuring partial logs resulted in fewer void strips than measuring butts only, especially in cutovers with low residue density. Therefore, the precision of the butts only system should be lower than for the partial logs measurement when using strips. This was the case in this study.

Table 5-1. Total sample size and void samples for measuring residue density by partial logs and butts only for 10 sampling trials using 1 m wide strips.

Cutover	Number of Void Sample Units in 10 Trials: Partial Logs Plot					Butts Only Plot					Total Sample Size (n)
CRO.	0	3	1	1	0	8	14	10	14	13	
	1	1	0	1	0	13	12	14	8	10	32
DUB.	11	11	7	7	7	19	22	17	24	21	
	8	6	11	9	7	20	21	25	25	23	32
PAU.	12	14	12	12	14	38	38	36	37	34	
	14	18	13	15	13	36	35	39	37	33	44
BAN.	5	3	5	7	11	18	22	28	25	20	
	11	2	8	5	10	26	23	31	22	23	52
GIL1	5	4	5	5	4	23	23	20	25	22	
	4	5	5	7	2	25	29	28	23	30	52
GIL2	0	2	1	0	2	6	8	7	7	10	
	3	2	0	2	0	8	8	9	11	13	32

Table 5-2 lists numbers of sample units containing residue when measuring butts only on circular plots and when enumerating circular transects. These results show that less than 25 percent of the circular transects and 13 percent of the plots contained residue. Therefore the transects should result in a higher level of precision of estimation than the plots, as was found in this study.

Table 5-2. Total sample size and occupied residue samples using circular transects and measuring butts only on 2 m radius circular plots for 10 sampling trials.

Cutover	Numbers of Sample Units Containing Residue in 10 Trials: Circular Transect					Butts Only Plot					Total Sample Size (n)
CRO.	69	82	69	73	67	28	35	24	31	33	
	70	73	77	72	69	26	34	32	26	31	407
DUB.	33	31	40	35	36	12	10	12	14	8	
	32	34	29	42	38	10	19	9	13	16	407
PAU.	32	24	32	24	27	9	10	9	10	11	
	27	30	24	33	29	14	9	8	16	12	420
BAN.	69	78	76	69	75	35	38	38	29	36	
	82	79	94	82	72	53	42	42	53	41	413
GIL1.	96	87	95	97	94	37	32	42	38	53	
	101	97	94	101	97	45	38	53	45	38	413
GIL2.	86	72	72	76	87	42	26	30	36	42	
	79	74	86	77	82	37	35	28	35	42	407

For all four systems listed above, a large improvement in precision could be expected if the void sample units are separated from the occupied units for analysis. This is easily accomplished using poststratification of sample units.

When using stratified sampling to estimate mean residue density, only occupied sample units are used for calculating sampling precision of strata containing residue. In this study, variation among occupied sample units when measuring butts only was less than among units where partial logs were measured or for transects. This trend was especially true when small sample units were used. This situation led to higher precision of estimation for stratified RS measuring butts only over SRS.

Poststratification using RS would be expected to give approximately the same results as stratified RS, if the poststratified strata weights are correct. However, when applying RS with poststratification to residue sampling in areas with low densities of residue, the stratum weights derived from sampling using butts only measurements of residue on strata, were not necessarily correct. This is demonstrated as follows.

When using RS with poststratification to estimate mean density of residue for populations, the poststratified RS and the SRS obtained the same estimated values for mean density (Table 4-20a). Since SRS measuring butts only on plots sampled a large number of void units, it obtained low estimation precision for mean density of residue because of the void samples resulting in poor sampling precision for estimating residue density. This results in wide confidence intervals for the estimated mean. With the more precise mean estimates from poststratified RS, the confidence intervals were much narrower and did not always contain the population mean. Therefore, RS with poststratification when measuring butts only achieved precise but often biased estimates because the stratum weights derived from sampling were not correct in this study. This can be further demonstrated by comparing Table 5-2 with Figure 4-12.

In Figure 4-12, higher relative errors indicate that too few or too many occupied (residue) sample units were selected during the sampling trials. Hence, the low sampling precision of estimates when measuring butts only on plots resulted in inaccurate estimates of stratum weights. For example, measuring butts only on plots sampled abnormal numbers of residue plots at sampling trials 6 and 9 in Paudush cutover (see Table 5-2). When checking these two trials in Figure 4-12c, we can find corresponding abnormally high relative errors of mean density of residue. Therefore, precision of estimating weights for the occupied stratum is critical to RS with poststratification.

Cochran (1977) pointed out that for determining a proportion of sample units showing an attribute where only 1 percent of units within a population have the attribute, a random sample size of 9801 has to be used in order to estimate the proportion with a coefficient of variation of 10 percent. He also concluded that "simple random sampling, or any method of sampling that is adapted for general purposes, is an expensive method of estimating the total number of units of a scarce type." According to Cochran's (1977) calculations, for a population with 20 percent of the units having the attribute of interest, 400 units must be sampled to achieve a 10 percent coefficient of variation for this proportion. When dealing with a sample frame where 10 percent of the units show the attribute, approximately 900 samples will be required to provide the 10 percent coefficient of the variation.

In this study, 20 percent SI was simulated in 10 sampling trials using both circular transects and for measuring butts only on plots as shown in Table 5-2. Based on poststratification of units for the butts only measurement using plots, less than 13 percent and usually less than 10 percent of the sample units contained residue. With the sample frames using circular transects, less than 10 percent of the sample units in Dublin and Paudush cutovers contained residue. Therefore these populations require sample intensities of 900 or more units in order to achieve adequate estimates of stratum weights. However, less than or equal to 420 plots were sampled in those trials. This explains why the estimates of residue density when measuring butts only in plots or when measuring circular transects in the Dublin and Paudush areas were less precise than for the other sampling situations described in Table 5-2. All the other circular transect sample frames had over 16 and usually closer to 20 percent of the sample units containing residue.

Partial Logs Plots Versus Butts Only Plots

Measuring partial logs on plots requires less SI than measuring butts only, especially when using small sample units (Tables 4-13a and b). The measurement of partial logs divides residue crossing plot boundaries into several shorter segments. Plots counted as voids when measuring butts only became occupied sample units if they contained a partial log. This reduced the total number of void sample units when counting partial logs and lead to improved sampling precision for estimating the proportion of sample units containing residue. As smaller plots include proportionally more boundary pieces but fewer butts compared to larger units, smaller plots counting partial logs are expected to show higher precision than when measuring butts only.

For the same reason, measuring partial logs on narrow strips can also improve sampling precision over counting butts only when estimating residue density or stratum weights.

Reliable Minimum Estimate(RME)

When standard error is higher than 20 percent of the estimated mean, the mean has little practical value because its relative precision will be exceeded by 40 percent. However, in this study, estimated standard errors of residue density were relatively small compared to their estimated means, with the result that these estimates were often very close to their corresponding real values. Since one purpose of this project was to find surveying methods for determining instances where merchantable harvesting residue levels exceeded allowable limits, the RME method should satisfy this objective. If the OMNR can ensure that a RME for residue density is less than its true value based on probability sampling, any company should accept it. Therefore, the RME method can be used for the purpose of cutover inspection.

For example, the Paudush cutover has the lowest mean density of residue at 17.42 pieces/ha. In simulated sampling trial two, the mean density estimated by using circular transects was 12.99 pieces/ha, which is the lowest estimate of mean density for the Paudush cutover. The relative error of this mean is about 25.4 percent. Although the 25.4 percent relative error sounds very large, the absolute error for the mean is less than 5 pieces/ha. When using post-stratified RS with 99 percent confidence, the RME is about 10.55 pieces/ha, which is greater than the acceptable maximum of 10 (pieces/ha) defined by the OMNR. By comparison, sampling trial nine estimated the highest mean value at 20.77 pieces/ha. The relative error of this second mean is 19.23 percent, giving an absolute error of 3.35 pieces/ha and a RME of 16.18 pieces/ha. This is less than the true mean of 17.42 pieces/ha and should be acceptable in identifying an unacceptably high level of residue.

In summary, the major problem experienced in residue sampling in northeastern Ontario may be attributed to the low residue density expected in any cutover. This is especially true if the residue is distributed in a clustered manner. This was the situation experienced in all areas included in this study.

According to the results of the simulation, when the number of pieces were less than 30/ha, the expected total number of sample units required to meet a relative accuracy of 20 percent will be 900. This large number of samples prevents the use of double sampling to determine the proportion of a cutover occupied by residue. Measuring partial logs on plots or the use of long strip samples or transects can reduce the occurrence of void samples. However, these improvements are limited because of increased variation among residue plots or strips. Some plots or strips would have very large amounts of residue while some are expected to have quite small values, especially for low density residue populations with clumped distributions. Therefore, although poststratification with RS using circular transects can further improve sampling precision, it still cannot solve the problem of dealing with the rare item as in this study. Using RME methods for residue inspection could be useful in certain low density cutovers, but it cannot satisfy the very low density of residue occurrence: *e.g.* less than 15 pieces/ha. In addition, the results are based on 20 percent SI. For forest utilization surveys, much lower SI's are expected to be used, thereby none of the above methods is suitable for residue surveys on cutovers with very low densities and clustered spatial distributions of residue.

CONCLUSIONS

Based on previous research in residue sampling, two sampling designs (SRS and stratified RS) and ten sample units (measuring butts only and partial logs on strip, square and circular plots plus circular, single, double and triangular transects) were chosen and tested in both finite and infinite sample frames for six cutovers in northeastern Ontario. This is the first occurrence of applying computerized sampling simulation methods for residue sampling in real populations on small clearcut areas in the boreal forest of Ontario. The results of the repeated sampling simulations revealed a major problem for residue sampling in this region. The conclusions of this project can be summarized as follows.

Residue Population

Individual log-size residue are usually distributed in clustered patterns. The degree of clumping is strongly related to the amount of residue instead of different forest types, cutting seasons or logging methods in this study. The residue level (17 to 86 pieces/ha), in this region, may be high from a utilization point of view, but from a survey point of view, the level in the Paudush cutover (17 pieces/ha) is too low to detect *with reasonable sample size.*

Plot Shape and Size

Sample unit shape and size are very important when sampling populations which show clustered spatial distributions. Large size plots can be treated as a cluster of small size plots. Long narrow shaped cluster plots are the best for eliminating the effects of correlation between the adjacent small areas or population units. Of course, any two strips should be sufficiently far apart if parallel strip sampling is conducted to overcome this correlation effect. Since cluster sampling is effective only when variation within clusters is greater than that between clusters, residue sampling using longer sample strips or lines usually results in better estimates of residue density than circular or square sample units.

Basic Residue Sampling Methods

Measuring butts only on plots is the simplest way to survey residue, but it cannot be used in cutovers with a low density of log-size residue. This is due to the great variation among sample units, leading to low precision of estimation. Although the use of long narrow sample units can reduce the number of void samples, measuring butts only on strips still cannot reduce the variation sufficiently for precise results.

Measuring partial logs on plots can increase sampling precision and accuracy of estimates. Using long narrow strips and measuring partial logs results in estimates similar to those produced by line intersect sampling.

Because of orientation of individual pieces of residue, strip or line sampling may require increased sampling than indicated by precision requirements to ensure adequate accuracy when estimating residue density. This is especially true for line intersect sampling, which is strongly affected by residue piece orientation. Using single transects with random direction and circular transects could overcome this residue orientation problem. Circular transects reduce the opportunity for bias due to residue orientation, leading to better accuracy.

Systematic Sampling

Systematic sampling was compared with SRS in this study. The results of sampling accuracy show that there is no advantage of systematic sampling over SRS. The sample size recommended by the method used in the province of B.C. for measuring soil disturbance could not meet the requirement of logging residue sampling in this study.

Stratified Sampling

The difference between estimates of sampling precision based on all units versus occupied units revealed that sampling of void units is a major problem and leads to poor precision of estimation when sampling areas with low residue density. Stratifying a population into void and occupied units is a way to increase sampling precision.

Unfortunately, it is very difficult to obtain information on how spatially clustered a population is before sampling. Therefore, high intensity sampling using small plots to estimate the proportions of occupied and void sample units precisely in a cutover, combined with poststratified sampling of residue may be very helpful in populations with high proportions of void units. When a cutover area is easy to walk and when the travel cost between plots is cheaper than that of surveying plots, this method should be applicable.

When sampling a cutover with a low density of residue, measuring butts only is not suitable because of the low proportion of occupied units. Measuring partial logs on plots and using circular transect methods will improve the precision of estimating the proportion of occupied units. This is because these sample units increase the frequency of observation of residue and reduce the variation between sample units. However, the improvement is limited by the total residue density in a cutover. Simulation results with 20 percent sampling intensity here suggest an approximate threshold value for precise estimation of 60 pieces/ha when using RS with poststratification on cutovers with clustered distributions of residue. But this amount of residue is too high to meet the criteria in the Crown Timber Act (Government of Ontario 1985) and would not be expected to occur in a normal cutover in northeastern Ontario. Using the RME could detect a cutover with 20 pieces/ha of merchantable residue which exceeds the penalty level of 10 pieces/ha. It cannot be used to detect cutovers with residue levels close to the penalty level.

RECOMMENDATIONS

Although this research did not reach the expected goal and obtain a precise sampling design for detecting low levels of merchantable residue, the products of the study can be expected to have some impacts on residue sampling and forest utilization.

Residue Sampling

In order to avoid the piece orientation problem, two methods can be used rather than one long straight line intersect for sampling. These are the SRS measuring partial logs on strips and the RS with poststratification using circular transects.

Rare item Sampling

Rare item sampling not only occurs in the assessment of merchantable logging residue, but also happens for sampling other populations (Cochran 1977). Principles for increasing precision of sampling for rare items are: 1) to reduce variation among sample units; and 2) to reduce sampling of void sample units. Therefore, strip sampling with partial logs measurement and line intersect sampling methods are recommended for residue sampling and horizontal point sampling combined with stratified sampling is recommended for surveying standing residue or stands of low density.

However, the precision of methods for rare item sampling are limited to the number of rare items per hectare and their spatial distribution pattern. None of the sampling techniques tested was adequate for estimating logging residue when the residue density is low (less than 60 pieces/ha) and the residue is very clustered spatially.

Forest Utilization

Since no suitable sampling methods were found for very low density, merchantable residue sampling, some alternative forest management choices should be considered for better utilization of forest production.

One is the RME method with poststratified RS. In this study, simulation with 20 percent sampling intensity at the 99 percent confidence level showed that when the mean density of residue is greater than 17 pieces/ha, the RME always exceeded the penalty level in this study.

Another method is to survey whole cutovers. From one corner of a cutover, check every piece of residue and stop at the penalty scale. For a cutover with double the amount of residue of the penalty scale, sampling intensities may include 50 percent of the area in question.

A third alternative is to conduct a statistically justifiable operational inventory before harvesting for determining the RME of timber volume in areas with accessibility. The royalty charges would then be based on the RME. Any timber volume in excess of the RME would not have royalties charged, thus encouraging better utilization. This should encourage no logging waste.

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APPENDIX A: CHI-SQUARE TEST FOR EQUALITY OF FREQUENCY AND PROPORTIONS OF RESIDUE TYPES AMONG SAMPLED AREAS.

It is assumed that the density and proportions of residue types, sawlogs, pulpwood and standing residuals are the same between tested cutover areas. Residue density by type is used for identifying differences between cutovers using χ^2 tests. Observed residue frequency is defined as "Fo" and theoretical frequency is defined as "Ft" (Berenson and Levine 1983).

Table A-1. Chi-square test for Crothers-1 and Crothers-2 areas.

Area		Log	Tree	Pulpwood	Stump	Totals
1	Fo	45.80	2.40	77.80	11.70	137.70
	Ft	31.13	3.66	85.16	17.75	
2	Fo	31.70	6.70	134.20	32.50	205.10
	Ft	46.37	5.44	126.84	26.45	
Totals		77.50	9.10	212.00	44.20	342.80

$\chi^2 = 16.7869 > \chi^2(0.05,3) = 7.8150$

Therefore, differences between the Crothers-1 area and Crothers-2 area are significant at the 95 percent confidence level.

Table A-2. Chi-square test for Paudush-1 and Paudush-2 areas.

Area		Log	Tree	Pulpwood	Stump	Totals
1	Fo	31.49	4.57	25.72	0.72	62.50
	Ft	31.18	15.01	15.74	0.57	
2	Fo	36.46	28.13	8.59	0.52	73.70
	Ft	36.77	17.69	18.57	0.67	
Totals		67.95	32.70	34.31	1.24	136.20

$\chi^2 = 25.1722 \quad > \quad \chi^2(0.05,3) = \quad 7.8150$

Therefore, differences between the Paudush-1 area and paudush-2 area are significant at the 95 percent confidence level.

Table A-3. Chi-square test for Bannerman areas.

Area		Log	Tree	Pulpwood	Stump	Totals
1	Fo	26.20	1.92	58.17	0.72	87.01
	Ft	31.47	2.87	51.56	1.12	
2	Fo	45.45	5.68	95.46	3.41	150.00
	Ft	54.24	4.94	88.89	1.93	
3	Fo	74.00	5.00	69.00	2.00	150.00
	Ft	54.24	4.94	88.89	1.93	
4	Fo	27.08	3.13	60.42	0.00	90.63
	Ft	32.77	2.98	53.71	1.16	
Totals		172.73	15.73	283.05	6.13	477.64

$\chi^2 = 19.9961 \quad > \quad \chi^2(0.05,9) = \quad 16.9190$

Therefore, differences among the Bannerman areas are significant at the 95 percent confidence level.

Table A-4. Chi-square test for Bannerman-1 and Bannerman-4 areas.

Area		Log	Tree	Pulpwood	Stump	Totals
1	Fo	26.20	1.92	58.17	0.72	87.01
	Ft	31.47	2.87	51.56	1.12	
4	Fo	27.08	3.13	60.42	0.00	90.63
	Ft	32.77	2.98	53.71	1.16	
Totals		53.28	5.05	118.59	0.72	177.64

$\chi^2 = 0.9938 < \chi^2(0.05,3) = 7.8150$

Therefore, differences between the Bannerman-1 and Bannerman-2 areas are not significant at the 95 percent confidence level.

Table A-5. Chi-square test for Gill-1a, Gill-2 and Gill-3 areas.

Area		Log	Tree	Pulpwood	Stump	Totals
1	Fo	25.00	0.00	63.13	0.62	88.75
	Ft	28.48	1.80	58.27	0.21	
2	Fo	40.83	3.75	61.67	0.00	106.25
	Ft	34.10	2.15	69.75	0.25	
3	Fo	20.27	1.69	51.35	0.00	73.31
	Ft	23.52	1.49	48.13	0.17	
Totals		86.10	5.44	176.15	0.62	268.31

$\chi^2 = 8.0282 < \chi^2(0.05,6) = 12.5920$

Therefore, differences among the Gill-1a, Gill-2 and Gill-3 areas are not significant at the 95 percent confidence level.

APPENDIX B: RESULTS OF STRATIFIED SAMPLING MEASURING BUTTS ONLY AND PARTIAL LOGS ON SAMPLE STRIPS.

Stratified random sampling measuring butts only and partial logs strips were tested for 1, 2 and 5 m wide strips. Sampling intensities of 20 percent were applied in 10 trials conducted in finite sample frames for six cutovers.

Table B-1. Stratified sampling measuring butts only on sample strips in Crothers cutover.

Strip width = 5 m

Trial	Sample Frame			Residue Sample Frame		
	Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
1	77.08	86.806	6	77.08	86.806	6
2	68.75	81.25	6	68.75	81.25	6
3	58.33	122.222	6	58.33	122.222	6
4	52.08	36.806	6	52.08	36.806	6
5	68.75	181.25	6	68.75	181.25	6
6	66.67	63.889	6	66.67	63.889	6
7	77.08	120.139	6	77.08	120.139	6
8	62.5	91.667	6	62.5	91.667	6
9	75	158.333	6	75	158.333	6
10	72.92	178.472	6	72.92	178.472	6
Strip Width = 2 m						
1	62.5	97.656	16	66.67	95.734	15
2	76.17	97.453	16	81.25	87.798	15
3	70.31	61.849	16	70.31	61.849	16
4	60.55	100.708	16	69.2	95.97	14
5	54.69	48.828	16	58.33	43.651	15
6	62.5	71.615	16	66.67	65.972	15
7	50.78	77.311	16	54.17	77.877	15
8	50.78	70.801	16	58.04	67.455	14
9	54.69	55.339	16	58.33	51.091	15
10	64.45	120.239	16	68.75	120.536	15
Strip Width = 1 m						
1	82.03	128.764	32	109.38	127.378	24
2	48.83	86.532	32	86.81	125.386	18
3	62.5	75.605	32	90.91	63.951	22
4	62.5	138.609	32	111.11	195.171	18
5	74.22	166.567	32	125	201.023	19
6	52.73	63.693	32	88.82	42.321	19
7	56.64	77.869	32	90.63	73.602	20
8	62.5	138.609	32	111.11	195.171	18
9	68.36	77.869	32	91.15	67.699	24
10	68.36	115.671	32	99.43	130.67	22

Table B-2. Stratified sampling measuring butts only on sample strips in Dublin cutover.

Strip width = 5 m

Trial	Sample Frame			Residue Sample Frame		
	Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
1	29.17	80.556	6	29.17	80.556	6
2	20.83	13.889	6	20.83	13.889	6
3	25	8.333	6	25	8.333	6
4	18.75	47.917	6	28.13	49.479	4
5	31.25	72.917	6	31.25	72.917	6
6	10.42	11.806	6	15.63	7.813	4
7	22.92	11.806	6	22.92	11.806	6
8	33.33	88.889	6	40	80	5
9	35.42	78.472	6	35.42	78.472	6
10	27.08	28.472	6	27.08	28.472	6
			Strip width = 2 m			
1	27.34	64.29	16	62.5	74.405	7
2	31.25	39.062	16	45.45	33.574	11
3	31.25	26.042	16	41.67	15.783	12
4	19.53	51.27	16	62.5	78.125	5
5	15.62	19.531	16	35.71	15.944	7
6	17.58	32.349	16	46.87	39.062	6
7	37.11	73.039	16	59.37	77.257	10
8	25.39	40.487	16	45.14	45.814	9
9	44.92	71.411	16	65.34	49.07	11
10	27.34	83.822	16	72.92	138.889	6
			Strip width = 1 m			
1	31.25	44.103	32	76.92	46.228	13
2	25.39	49.517	32	81.25	142.361	10
3	31.25	31.502	32	66.67	13.889	15
4	17.58	26.678	32	70.31	48.828	8
5	31.25	69.304	32	90.91	191.116	11
6	29.3	44.004	32	78.12	53.267	12
7	27.34	50.009	32	79.55	118.802	11
8	19.53	46.859	32	89.29	276.361	7
9	15.62	25.202	32	71.43	63.775	7
10	25.39	55.818	32	90.28	183.256	9

Table B-3. Stratified sampling measuring butts only on sample strips in Paudush cutover.

Strip width = 5 m

Trial	Sample Frame			Residue Sample Frame		
	Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
1	18.75	19.345	8	25	11.111	6
2	29.17	93.254	8	33.33	105.82	7
3	12.5	13.889	8	20	8.889	5
4	18.75	114.583	8	37.5	347.222	4
5	31.25	122.52	8	41.67	159.259	6
6	18.75	11.409	8	21.43	7.559	7
7	14.58	11.409	8	19.44	6.173	6
8	8.33	7.937	8	16.67	0	4
9	25	111.111	8	40	191.111	5
10	14.58	19.345	8	23.33	13.333	5
Strip width = 2 m						
1	17.05	40.038	22	62.5	162.037	6
2	28.41	68.461	22	69.44	154.321	9
3	15.15	15.305	22	41.67	0	8
4	22.73	46.46	22	62.5	99.206	8
5	15.15	33.342	22	55.56	154.321	6
6	5.68	7.789	22	41.67	0	3
7	28.41	62.448	22	62.5	131.173	10
8	18.94	58.485	22	69.44	339.506	6
9	30.3	85.268	22	74.07	222.908	9
10	15.15	21.317	22	47.62	28.345	7
Strip width = 1 m						
1	17.05	56.258	44	125	1388.889	6
2	13.26	23.157	44	97.22	154.321	6
3	17.05	26.894	44	93.75	86.806	8
4	15.15	25.092	44	95.24	113.379	7
5	26.52	69.137	44	116.67	518.518	10
6	18.94	34.435	44	104.17	148.81	8
7	18.94	28.563	44	92.59	68.587	9
8	9.47	13.013	44	83.33	0	5
9	17.05	32.767	44	107.14	188.964	7
10	26.52	63.265	44	106.06	413.223	11

Table B-4. Stratified sampling measuring butts only on sample strips in Bannerman cutover.

Trial	Sample Frame Mean pieces/ha	Sample Frame Variance of Mean	Sample Frame Sample Size	Residue Sample Frame Mean pieces/ha	Residue Sample Frame Variance of Mean	Residue Sample Frame Sample Size
	Strip width = 5 m					
1	96	418.133	10	96	418.133	10
2	74	491.022	10	82.22	546.173	9
3	74	142.578	10	74	142.578	10
4	80	263.111	10	88.89	249.877	9
5	86	498.133	10	95.56	531.358	9
6	116	389.689	10	116	389.689	10
7	94	220.8	10	94	220.8	10
8	84	105.244	10	84	105.244	10
9	80	192	10	80	192	10
10	56	176.356	10	70	171.429	8
	Strip width = 2 m					
1	86.54	237.278	26	107.14	278.912	21
2	103.85	171.834	26	128.57	138.776	21
3	103.85	184.142	26	117.39	178.725	23
4	84.62	177.041	26	115.79	176.054	19
5	98.08	206.036	26	127.5	194.474	20
6	90.38	209.349	26	111.9	227.665	21
7	92.31	275.03	26	120	330.526	20
8	90.38	117.041	26	102.17	106.548	23
9	98.08	119.882	26	110.87	102.423	23
10	111.54	124.97	26	120.83	108.092	24
	Strip width = 1 m					
1	119.23	271.725	52	182.35	363.217	34
2	92.31	192.134	52	160	286.897	30
3	75	198.341	52	162.5	458.333	24
4	84.62	171.249	52	162.96	254.089	27
5	98.08	202.054	52	159.38	288.054	32
6	86.54	217.368	52	173.08	407.574	26
7	80.77	126.929	52	144.83	149.482	29
8	59.62	116.197	52	147.62	214.059	21
9	78.85	92.528	52	136.67	64.061	30
10	78.85	110.628	52	141.38	108.714	29

Table B-5. Stratified sampling measuring butts only on sample strips in Gill-1 cutover.

Strip width = 5 m

Trial	Sample Frame			Residue Sample Frame		
	Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
1	80	263.111	10	80	263.111	10
2	86	284.8	10	86	284.8	10
3	84	432.356	10	93.33	453.333	9
4	66	135.467	10	66	135.467	10
5	76	169.244	10	76	169.244	10
6	104	297.244	10	104	297.244	10
7	116	347.022	10	128.89	267.654	9
8	90	307.556	10	100	284.444	9
9	58	266.311	10	72.5	307.857	8
10	102	287.644	10	102	287.644	10
			Strip width = 2 m			
1	96.15	221.065	26	125	226.316	20
2	61.54	94.201	26	94.12	71.799	17
3	84.62	238.58	26	129.41	280.277	17
4	69.23	160.473	26	112.5	175	16
5	107.69	188.876	26	127.27	170.799	22
6	96.15	227.219	26	125	236.842	20
7	126.92	395.266	26	157.14	421.769	21
8	71.15	130.296	26	88.1	141.95	21
9	96.15	196.45	26	119.05	195.011	21
10	76.92	173.728	26	105.26	197.599	19
			Strip width = 1 m			
1	94.23	177.457	52	168.97	218.787	29
2	88.46	154.774	52	158.62	187.532	29
3	100	168.929	52	162.5	189.516	32
4	82.69	143.114	52	159.26	165.453	27
5	90.38	158.429	52	156.67	196.475	30
6	92.31	198.167	52	177.78	281.102	27
7	67.31	125.014	52	152.17	185.599	23
8	78.85	170.96	52	170.83	274.758	24
9	94.23	189.523	52	168.97	258.196	29
10	65.38	138.067	52	154.55	267.611	22

Table B-6. Stratified sampling measuring butts only on sample strips in Gill-2 cutover.

Strip width = 5 m

Trial	Sample Frame Mean pieces/ha	Sample Frame Variance of Mean	Sample Frame Sample Size	Residue Sample Frame Mean pieces/ha	Residue Sample Frame Variance of Mean	Residue Sample Frame Sample Size
1	106.25	222.917	6	106.25	222.917	6
2	81.25	189.583	6	81.25	189.583	6
3	97.92	78.472	6	97.92	78.472	6
4	77.08	20.139	6	77.08	20.139	6
5	91.67	238.889	6	91.67	238.889	6
6	64.58	111.806	6	64.58	111.806	6
7	93.75	106.25	6	93.75	106.25	6
8	87.5	58.333	6	87.5	58.333	6
9	91.67	80.556	6	91.67	80.556	6
10	89.58	161.806	6	89.58	161.806	6
			Strip width = 2 m			
1	76.17	182.088	16	81.25	184.524	15
2	97.66	227.051	16	104.17	220.734	15
3	72.27	134.888	16	77.08	132.937	15
4	83.98	199.992	16	89.58	199.901	15
5	82.03	161.947	16	87.5	157.738	15
6	87.89	138.143	16	87.89	138.143	16
7	78.13	78.125	16	78.13	78.125	16
8	64.45	87.687	16	68.75	83.333	15
9	74.22	103.353	16	74.22	103.353	16
10	70.31	120.443	16	75	117.56	15
			Strip width = 1 m			
1	85.94	74.03	32	105.77	45.858	26
2	83.98	129.847	32	111.98	124.311	24
3	85.94	124.433	32	110	117.5	25
4	78.12	94.506	32	100	83.333	25
5	68.36	128.272	32	99.43	157.726	22
6	68.36	77.869	32	91.15	67.699	24
7	85.94	168.536	32	114.58	188.708	24
8	76.17	143.236	32	105.98	165.943	23
9	87.89	219.628	32	133.93	272.109	21
10	83.98	218.053	32	141.45	271.237	19

Table B-7. Stratified sampling measuring partial logs on sample strips in Crothers cutover.

Strip width = 5 m

Trial	Sample Frame			Residue Sample Frame		
	Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
1	69.55	22.71	6	69.55	22.71	6
2	64.11	155.327	6	64.11	155.327	6
3	71.98	24.665	6	71.98	24.665	6
4	69.72	39.924	6	69.72	39.924	6
5	65.89	19.01	6	65.89	19.01	6
6	50.91	111.217	6	50.91	111.217	6
7	50.91	111.217	6	50.91	111.217	6
8	67.82	37.172	6	67.82	37.172	6
9	72.45	88.093	6	72.45	88.093	6
10	72.45	88.093	6	72.45	88.093	6
			Strip width = 2 m			
1	65.02	46.338	16	65.02	46.338	16
2	58.05	47.169	16	58.05	47.169	16
3	60.89	76.605	16	64.95	72.48	15
4	49.96	65.548	16	49.96	65.548	16
5	62.17	66.223	16	62.17	66.223	16
6	46.66	57.397	16	49.77	56.75	15
7	60.89	76.605	16	64.95	72.48	15
8	56.61	44.074	16	56.61	44.074	16
9	48.87	42.764	16	52.13	39.169	15
10	49.96	65.548	16	49.96	65.548	16
			Strip width = 1 m			
1	66.81	41.173	32	66.81	41.173	32
2	53.19	30.534	32	58.69	28.076	29
3	54.7	24.414	32	56.47	23.385	31
4	54.7	24.414	32	56.47	23.385	31
5	67.71	33.969	32	67.71	33.969	32
6	62.7	37.74	32	64.72	36.765	31
7	53.8	40.257	32	55.54	40.37	31
8	62.43	33.155	32	62.43	33.155	32
9	50.02	23.101	32	51.63	22.42	31
10	65.58	27.621	32	65.58	27.621	32

Table B-8. Stratified sampling measuring partial logs strips in Dublin cutover.

Strip width = 5 m

Trial	Sample Frame			Residue Sample Frame		
	Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
1	24.61	59.569	6	29.54	60.271	5
2	35.57	24.439	6	35.57	24.439	6
3	29.56	36.181	6	29.56	36.181	6
4	31.35	33.953	6	31.35	33.953	6
5	22.82	34.095	6	22.82	34.095	6
6	22.17	35.828	6	22.17	35.828	6
7	24.47	64.142	6	29.36	67.479	5
8	26.5	46.531	6	31.8	36.095	5
9	13.48	17.332	6	20.21	7.012	4
10	15.38	28.261	6	23.08	23.314	4
Strip width = 2 m						
1	29.23	28.091	16	33.4	28.46	14
2	30.23	48.299	16	37.21	57.001	13
3	28.32	26.995	16	37.77	23.15	12
4	38.43	42.928	16	43.92	41.768	14
5	26.06	31.106	16	34.74	34.607	12
6	26.78	23.756	16	32.96	22.971	13
7	22.36	13.816	16	27.52	11.791	13
8	38.43	42.928	16	43.92	41.768	14
9	18.55	17.482	16	32.98	10.677	9
10	22.31	22.803	16	32.45	23.427	11
Strip width = 1 m						
1	23.61	18.467	32	35.98	25.819	21
2	22.41	17.379	32	34.16	25.006	21
3	21.68	12.928	32	27.75	15.76	25
4	30.45	16.463	32	38.97	16.145	25
5	24.33	11.841	32	31.14	12.505	25
6	25.15	15.918	32	33.54	18.824	24
7	30.73	13.892	32	37.82	12.618	26
8	22.41	17.379	32	34.16	25.006	21
9	29.49	20.189	32	41.02	22.369	23
10	24.66	11.52	32	31.56	11.783	25

Table B-9. Stratified sampling measuring partial logs on sample strips in Paudush cutover.

Strip width = 5 m

Trial	Sample Frame			Residue Sample Frame		
	Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
1	12.19	29.906	8	19.5	55.228	5
2	12.51	9.327	8	14.29	9.032	7
3	15.06	15.022	8	17.21	15.09	7
4	11.93	12.283	8	13.63	13.281	7
5	7.84	7.008	8	10.46	8.706	6
6	18.88	23.766	8	25.17	19.022	6
7	23.26	27.231	8	23.26	27.231	8
8	15.09	28.355	8	17.25	32.847	7
9	14.62	9.541	8	16.7	8.071	7
10	17.02	20.684	8	22.69	18.012	6
			Strip width = 2 m			
1	14.98	9.212	22	21.97	11.488	15
2	15.59	8.861	22	21.44	10.373	16
3	13.78	17.195	22	21.65	33.16	14
4	18.76	16.083	22	27.52	21.615	15
5	15.38	10.91	22	26.02	13.84	13
6	18.16	10.994	22	21.02	12.173	19
7	20.64	12.909	22	26.71	13.817	17
8	12.19	4.869	22	15.78	5.442	17
9	15.59	8.861	22	21.44	10.373	16
10	15.38	5.963	22	21.15	4.971	16
			Strip width = 1 m			
1	16.32	6.462	44	22.44	8.779	32
2	15.44	4.666	44	22.65	5.646	30
3	20.86	10.214	44	28.68	13.691	32
4	20.86	10.214	44	28.68	13.691	32
5	15.6	8.408	44	22.88	13.692	30
6	15.69	7.39	44	23.01	11.423	30
7	15.69	9.134	44	26.55	17.36	26
8	14.7	6.727	44	20.87	10.255	31
9	17.91	9.094	44	27.18	13.997	29
10	19.71	10.929	44	27.97	16.07	31

Table B-10. Stratified sampling measuring partial logs on sample strips in Bannerman cutover.

Strip width = 5 m

Trial	Sample Frame			Residue Sample Frame		
	Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
1	82.31	136.399	10	82.31	136.399	10
2	77.76	229.128	10	86.4	211.763	9
3	85.24	411.262	10	94.71	424.376	9
4	73.47	141.763	10	73.47	141.763	10
5	89.38	215.591	10	89.38	215.591	10
6	95.97	321.461	10	106.63	288.131	9
7	92.82	254.704	10	92.82	254.704	10
8	80.53	183.902	10	80.53	183.902	10
9	85.24	411.262	10	94.71	424.376	9
10	85.24	411.262	10	94.71	424.376	9
			Strip width = 2 m			
1	69.89	97.779	26	79	99.417	23
2	66.36	66.525	26	78.42	57.55	22
3	82.17	110.771	26	85.46	110.639	25
4	89.87	143.509	26	97.36	143.626	24
5	86.4	139.655	26	89.86	140.941	25
6	82.11	92.019	26	85.39	90.339	25
7	86.4	139.655	26	89.86	140.941	25
8	98.58	208.517	26	102.52	212.417	25
9	82.11	92.019	26	85.39	90.339	25
10	93.8	111.221	26	101.61	103.34	24
			Strip width = 1 m			
1	82.38	75.612	52	91.15	78.857	47
2	87.16	51.614	52	92.5	49.97	49
3	82.38	75.612	52	91.15	78.857	47
4	77.33	66.802	52	89.35	69.932	45
5	75.26	74.975	52	95.45	82.692	41
6	66.68	56.827	52	84.58	61.631	41
7	94.99	69.806	52	98.79	69.434	50
8	91.22	101.612	52	107.81	109.162	44
9	94.49	75.662	52	104.54	74.534	47
10	65.99	45.98	52	81.71	45.761	42

Table B-11. Stratified sampling measuring partial logs on sample strips in Gill-1 cutover.

Strip width = 5 m

Trial	Sample Frame			Residue Sample Frame		
	Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
1	71.71	156.248	10	71.71	156.248	10
2	68.89	129.108	10	68.89	129.108	10
3	82.19	212.535	10	82.19	212.535	10
4	70.9	199.204	10	70.9	199.204	10
5	86.92	102.476	10	86.92	102.476	10
6	84.49	213.794	10	84.49	213.794	10
7	95.07	178.741	10	95.07	178.741	10
8	70.04	129.926	10	70.04	129.926	10
9	82.19	212.535	10	82.19	212.535	10
10	90.15	148.779	10	90.15	148.779	10
		Strip width = 2 m				
1	90.54	122.867	26	98.08	118.942	24
2	80.12	113.659	26	86.8	113.68	24
3	89	94.059	26	92.56	90.913	25
4	86.18	91.458	26	89.62	88.781	25
5	69.98	101.426	26	79.11	104.029	23
6	88.32	91.372	26	91.85	88.169	25
7	90.54	122.867	26	98.08	118.942	24
8	89	94.059	26	92.56	90.913	25
9	69.98	101.426	26	79.11	104.029	23
10	101.63	116.349	26	101.63	116.349	26
		Strip width = 1 m				
1	90	82.724	52	99.57	84.893	47
2	78.22	57.819	52	84.74	58.566	48
3	87.37	86.99	52	96.66	91.081	47
4	84.93	72.334	52	93.96	73.964	47
5	77.07	45.807	52	83.5	44.72	48
6	76.75	60.78	52	83.15	62.397	48
7	71.98	46.527	52	79.64	46.465	47
8	85.43	81.065	52	94.52	84.498	47
9	86.33	75.052	52	99.76	76.167	45
10	95.55	76.418	52	99.38	76.518	50

Table B-12. Stratified sampling measuring partial logs on sample strips in Gill-2 cutover.

Strip width = 5 m

Trial	Sample Frame			Residue Sample Frame		
	Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
1	80.68	83.246	6	80.68	83.246	6
2	72.36	57.504	6	72.36	57.504	6
3	70.87	14.76	6	70.87	14.76	6
4	89.49	65.204	6	89.49	65.204	6
5	92.04	110.255	6	92.04	110.255	6
6	92.04	110.255	6	92.04	110.255	6
7	98.94	57.506	6	98.94	57.506	6
8	92.04	110.255	6	92.04	110.255	6
9	82.6	69.616	6	82.6	69.616	6
10	88.51	175.17	6	88.51	175.17	6
			Strip width = 2 m			
1	60.69	70.392	16	60.69	70.392	16
2	88.33	109.862	16	88.33	109.862	16
3	60.7	39.383	16	60.7	39.383	16
4	71.29	50.859	16	71.29	50.859	16
5	78.67	111.249	16	78.67	111.249	16
6	86.01	62.905	16	86.01	62.905	16
7	79.88	80.264	16	79.88	80.264	16
8	94.63	110.283	16	94.63	110.283	16
9	66.46	109.684	16	66.46	109.684	16
10	78.67	111.249	16	78.67	111.249	16
			Strip width = 1 m			
1	87.33	97.181	32	87.33	97.181	32
2	66.1	68.486	32	70.51	69.519	30
3	79.44	56.287	32	82.01	54.435	31
4	88.93	88.19	32	88.93	88.19	32
5	66.1	68.486	32	70.51	69.519	30
6	67.87	58.17	32	74.89	56.042	29
7	73.65	58.77	32	78.56	56.371	30
8	71.41	51.819	32	71.41	51.819	32
9	80.84	77.935	32	86.23	76.044	30
10	87.33	97.181	32	87.33	97.181	32

APPENDIX C: POSTSTRATIFIED SAMPLING MEASURING BUTTS ONLY AND PARTIAL LOGS ON CIRCULAR PLOTS AND TRANSECTS.

Random sampling with poststratification when measuring partial logs (P) and butts only (B) on circular plots and using circular transects (C) were tested. The plot radii ranged from 2 to 5 m. Ten sampling trials with sampling intensities of 20 percent were conducted in the infinite sample frames for six cutovers.

Table C-1a. Results of using 2 m radius plots and circular transects for poststratified random sampling in Crothers cutover.

Trial	Method	Sample Frame			Residual Stratum Sample Frame		
		Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
	P	60.16	71.679	407	354.88	986.321	69
1	C	56.59	52.812	407	333.80	499.116	69
	B	60.61	132.747	407	881.04	2243.686	28
	P	64.23	70.549	407	318.78	753.332	82
2	C	62.71	50.456	407	311.24	300.276	82
	B	74.30	155.024	407	863.98	1459.609	35
	P	58.27	61.824	407	334.01	739.804	71
3	C	51.36	43.986	407	302.94	428.296	69
	B	46.93	86.552	407	795.77	0.000	24
	P	51.73	45.923	407	288.43	495.600	73
4	C	59.61	47.083	407	332.37	221.153	73
	B	64.52	131.541	407	847.12	1273.984	31
	P	59.16	73.545	407	354.06	1108.966	68
5	C	56.19	52.898	407	341.35	501.833	67
	B	70.39	148.753	407	868.12	1635.479	33
	P	61.11	77.041	407	355.29	1120.904	70
6	C	60.19	59.341	407	349.99	560.221	70
	B	54.75	115.251	407	856.99	1798.602	26
	P	57.25	56.749	407	319.19	622.874	73
7	C	58.98	48.745	407	328.83	300.060	73
	B	70.39	141.088	407	842.59	1062.401	34
	P	70.37	83.108	407	367.17	871.245	78
8	C	66.27	58.539	407	350.31	343.752	77
	B	66.48	134.743	407	845.51	1196.932	32
	P	58.60	56.985	407	331.26	569.905	72
9	C	60.53	55.978	407	342.15	452.324	72
	B	52.79	104.273	407	826.38	936.771	26
	P	57.75	68.902	407	335.76	1004.395	70
10	C	54.59	49.342	407	332.02	471.285	69
	B	64.52	131.541	407	847.12	1273.982	31

Table C-1b. Results of using 3 m radius plots and circular transects for poststratified random sampling in Crothers cutover.

Trial	Method	Sample Frame			Residual Stratum Sample Frame		
		Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
	P	61.35	94.089	181	191.46	490.217	58
1	C	63.26	71.668	181	212.02	220.693	54
	B	66.44	129.055	181	387.9	364.46	31
	P	67.38	71.667	181	203.28	191.38	60
2	C	69.55	75.185	181	220.85	170.721	57
	B	54.71	106.231	181	380.88	355.279	26
	P	42.89	43.792	181	158.45	225.183	49
3	C	53.34	52.904	181	201.14	131.501	48
	B	50.8	116.2	181	417.98	886.101	22
	P	63.77	108.686	181	226.33	652.795	51
4	C	55.51	57.61	181	205.06	159.166	49
	B	62.53	139.534	181	419.17	725.951	27
	P	69.07	113.526	181	250.03	586.293	50
5	C	68.61	114.71	181	269.97	597.372	46
	B	68.39	169.825	181	442.1	1199.586	28
	P	55.05	70.493	181	195.36	352.402	51
6	C	50.27	48.319	181	185.71	145.345	49
	B	52.76	103.558	181	381.97	383.603	25
	P	79.01	147.91	181	250.89	739.607	57
7	C	62.44	81.009	181	226.03	322.599	50
	B	76.21	132.831	181	372.8	177.667	37
	P	59.36	69.206	181	198.96	263.745	54
8	C	52.69	51.554	181	198.69	127.291	48
	B	70.34	141.443	181	397.89	441.338	32
	P	60.42	85.495	181	206.33	431.705	53
9	C	54.66	60.803	181	197.87	230.275	50
	B	62.53	139.534	181	404.2	898.212	28
	P	58.71	76.46	181	200.52	357.065	53
10	C	58.58	63.121	181	216.38	162.987	49
	B	70.34	141.443	181	397.89	441.338	32

Table C-1c. Results of using 4 m radius plots and circular transects for poststratified random sampling in Crothers cutover.

Trial	Method	Sample Frame Mean pieces/ha	Sample Frame Variance of Mean	Sample Frame Sample Size	Residual Stratum Sample Frame Mean pieces/ha	Residual Stratum Sample Frame Variance of Mean	Residual Stratum Sample Frame Sample Size
	P	64.84	144.871	101	163.72	522.874	40
1	C	61.53	87.603	101	163.53	178.473	38
	B	55.15	118.491	101	242.19	306.073	23
	P	62.05	89.493	101	145.75	210.034	43
2	C	72.2	123.375	101	186.98	276.045	39
	B	63.03	132.692	101	235.79	342.455	27
	P	63.47	123.462	101	152.62	392.261	42
3	C	66.34	85.571	101	163.41	130.41	41
	B	55.15	118.491	101	242.19	306.073	23
	P	59.68	76.157	101	147.02	147.985	41
4	C	61.19	90.772	101	162.63	206.165	38
	B	63.03	148.366	101	265.26	382.402	24
	P	71.09	128.316	101	166.98	336.375	43
5	C	62.53	94.628	101	166.2	214.064	38
	B	68.94	160.161	101	267.81	358.315	26
	P	58.27	65.538	101	127.95	121.666	46
6	C	64.39	83.219	101	151.23	152.686	43
	B	61.06	107.705	101	220.26	140.23	28
	P	48.05	66.107	101	131.17	198.416	37
7	C	59.25	100.503	101	187.02	252.503	32
	B	47.27	110.887	101	251.3	426.362	19
	P	79.82	153.454	101	171.53	374.92	47
8	C	76.34	125.619	101	183.58	256.622	42
	B	66.97	119.733	101	225.47	157.708	30
	P	51.47	72.311	101	133.3	205.784	39
9	C	49.31	61.004	101	142.29	128.647	35
	B	53.18	108.869	101	223.81	331.614	24
	P	59.92	98.576	101	159.26	280.529	38
10	C	68.82	131.459	101	193.09	368.232	36
	B	47.27	95.212	101	227.36	242.318	21

Table C-1d. Results of using 5 m radius plots and circular transects for poststratified random sampling in Crothers cutover.

Trial	Method	Sample Frame: Mean pieces/ha	Sample Frame: Variance of Mean	Sample Frame: Sample Size	Residual Stratum Sample Frame: Mean pieces/ha	Residual Stratum Sample Frame: Variance of Mean	Residual Stratum Sample Frame: Sample Size
	P	42.08	88.045	65	97.69	283.28	28
1	C	44.43	65.756	65	115.51	113.816	25
	B	45.05	104.679	65	162.69	297.268	18
	P	51.27	75.708	65	119.02	117.959	28
2	C	58.21	135.59	65	151.36	352.688	25
	B	39.18	92.928	65	159.15	337.737	16
	P	64.75	112.063	65	127.53	191.231	33
3	C	49.59	75.486	65	119.37	126.921	27
	B	62.68	102.28	65	145.51	116.408	28
	P	54.25	95.97	65	100.75	197.71	35
4	C	66.94	141.261	65	145.04	284.868	30
	B	47.01	82.376	65	145.51	99.253	21
	P	69.23	106.564	65	115.38	159	39
5	C	49.76	73.725	65	111.53	131.637	29
	B	60.72	117.748	65	157.88	177.244	25
	P	70.14	120.117	65	130.27	189.548	35
6	C	54.84	111.618	65	142.58	252.655	25
	B	66.6	133.336	65	173.16	155.629	25
	P	43.36	66.053	65	97.19	151.549	29
7	C	39.24	47.018	65	98.11	69.908	26
	B	35.26	81.896	65	152.79	339.667	15
	P	57.99	76.561	65	107.7	110.195	35
8	C	64.41	115.44	65	135.06	198.332	31
	B	62.68	125.662	65	162.97	190.214	25
	P	72.4	189.274	65	138.42	424.861	34
9	C	63.72	128.385	65	138.06	260.001	30
	B	62.68	203.602	65	194.02	742.563	21
	P	59.39	69.385	65	110.3	77.411	35
10	C	46.13	64.609	65	115.34	94.242	26
	B	66.6	102.161	65	149.28	82.613	29

Table C-2a. Results of using 2 m radius plots and circular transects for poststratified random sampling in Dublin cutover.

Trial	Method	Sample Frame			Residual Stratum Sample Frame		
		Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
	P	19.75	14.362	407	243.63	542.846	33
1	C	22.2	18.245	407	273.76	702.703	33
	B	23.46	44.632	407	795.77	0	12
	P	17.39	13.391	407	228.31	774.2	31
2	C	21.84	18.686	407	286.76	787.926	31
	B	19.55	37.382	407	795.77	0	10
	P	28.69	28.087	407	299.37	999.181	39
3	C	29.15	23.928	407	296.59	500.588	40
	B	23.46	44.632	407	795.77	0	12
	P	25.71	24.965	407	298.92	1064.634	35
4	C	25.03	21.611	407	291.04	723.836	35
	B	27.37	51.807	407	795.77	0	14
	P	23.18	20.716	407	262.07	928.155	36
	C	24.04	17.935	407	271.78	428.346	36
	B	15.64	30.056	407	795.77	0	8
	P	20.71	14.953	407	263.43	428.214	32
6	C	23.43	20.965	407	297.98	853.214	32
	B	21.51	48.68	407	875.35	6332.573	10
	P	20.71	20.011	407	247.95	1239.71	34
7	C	22.24	18.207	407	266.21	713.335	34
	B	37.15	69.414	407	795.77	0	19
	P	17.53	21.246	407	254.86	2403.645	28
8	C	21.85	20.93	407	306.7	1139.189	29
	B	21.51	56.346	407	972.61	13681.49	9
	P	30.1	30.446	407	291.72	1060.213	42
9	C	29.94	24.17	407	290.13	478.244	42
	B	27.37	59.471	407	856.99	3747.084	13
	P	23.32	20.282	407	249.74	855.329	38
10	C	22.05	15.134	407	236.12	412.472	38
	B	33.24	70.093	407	845.51	2473.66	16

Table C-2b. Results of using 3 m radius plots and circular transects for poststratified random sampling in Dublin cutover.

Trial	Method	Sample Frame Mean pieces/ha	Sample Frame Variance of Mean	Sample Frame Sample Size	Residual Stratum Sample Frame Mean pieces/ha	Residual Stratum Sample Frame Variance of Mean	Residual Stratum Sample Frame Sample Size
	P	23.22	28.875	181	191.08	508.947	22
1	C	20.06	20.151	181	165.03	281.816	22
	B	21.49	47.346	181	389.05	1250.879	10
	P	18.72	20.297	181	169.45	396.046	20
2	C	15.45	14.919	181	155.33	310.382	18
	B	21.49	39.667	181	353.68	0	11
	P	29.9	28.133	181	150.32	210.264	36
3	C	32.34	30.609	181	167.23	174.53	35
	B	19.54	36.273	181	353.68	0	10
	P	18.72	20.297	181	169.45	396.046	20
4	C	15.45	14.919	181	155.33	310.382	18
	B	21.49	39.667	181	353.68	0	11
	P	27.32	44.716	181	197.79	1023.246	25
5	C	26.91	30.501	181	202.91	247.452	24
	B	23.45	58.376	181	424.41	2223.784	10
	P	28.29	43.576	181	182.89	830.729	28
6	C	24.98	23.939	181	161.48	215.313	28
	B	29.31	60.497	181	378.94	638.203	14
	P	18.72	20.297	181	169.45	396.046	20
7	C	15.45	14.919	181	155.33	310.382	18
	B	21.49	39.667	181	353.68	0	11
	P	20.97	25.829	181	158.14	581.322	24
8	C	22.67	24.751	181	170.99	358.225	24
	B	21.49	39.667	181	353.68	0	11
	P	22.19	23.168	181	148.76	351.052	27
9	C	21.26	20.375	181	153.95	255.225	25
	B	21.49	39.667	181	353.68	0	11
	P	32.82	55.137	181	212.15	967.11	28
10	C	26.96	26.527	181	168.27	215.081	29
	B	29.31	52.818	181	353.68	0	15

Table C-2c. Results of using 4 m radius plots and circular transects for poststratified random sampling in Dublin cutover.

Trial	Method	Sample Frame			Residual Stratum Sample Frame		
		Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
	P	19.23	28.748	101	97.13	365.875	20
1	C	18.87	19.306	101	105.91	95.047	18
	B	17.73	32.125	101	198.94	0	9
	P	32.18	53.105	101	120.38	355.655	27
2	C	33.57	43.383	101	130.41	168.977	26
	B	41.36	88.694	101	232.1	323.354	18
	P	17.45	23.253	101	97.89	304.259	18
3	C	22.23	33.319	101	124.76	347.332	18
	B	21.67	54.085	101	243.15	855.093	9
	P	30.76	50.482	101	163.51	284.922	19
4	C	26.09	42.353	101	146.41	361.753	18
	B	21.67	46.248	101	218.84	395.786	10
	P	16.69	25.052	101	112.4	436.505	15
5	C	13.78	19.269	101	99.39	414.774	14
	B	9.85	26.461	101	248.68	2473.662	4
	P	28.48	51.203	101	143.81	487.937	20
6	C	19.92	22.644	101	105.89	162.966	19
	B	25.61	60.06	101	235.12	588.772	11
	P	16.64	28.226	101	105.01	569.153	16
7	C	25.43	54.407	101	160.55	843.402	16
	B	17.73	55.637	101	255.78	3230.905	7
	P	24.1	37.115	101	115.92	360.379	21
8	C	27.24	49.577	101	137.57	518.859	20
	B	25.61	75.735	101	258.63	1803.025	10
	P	16.33	18.453	101	91.63	203.208	18
9	C	16.63	16.664	101	98.78	111.531	17
	B	21.67	46.248	101	218.84	395.786	10
	P	29.27	50.761	101	123.18	425.871	24
10	C	36.11	58.109	101	158.57	277.21	23
	B	39.39	117.715	101	306.07	819.675	13

Table C-2d. Results of using 5 m radius plots and circular transects for poststratified random sampling in Dublin cutover.

Trial	Method	Sample Frame Mean pieces/ha	Sample Frame Variance of Mean	Sample Frame Sample Size	Residual Stratum Sample Frame Mean pieces/ha	Residual Stratum Sample Frame Variance of Mean	Residual Stratum Sample Frame Sample Size
	P	30.98	48.009	65	83.9	168.741	24
1	C	35.81	44.696	65	96.99	78.837	24
	B	39.18	85.134	65	159.15	202.642	16
	P	26.92	35.796	65	79.55	122.974	22
2	C	31.21	45.881	65	96.61	138.563	21
	B	29.38	52.759	65	136.42	82.711	14
	P	28.11	54.956	65	91.34	297.603	20
3	C	31.78	73.33	65	108.71	427.339	19
	B	35.26	74.102	65	152.79	185.273	15
	P	21.7	42.357	65	100.77	355.317	14
4	C	18.23	47.739	65	107.74	841.129	11
	B	19.59	40.768	65	141.47	200.141	9
	P	26.09	32.951	65	80.75	105.694	21
5	C	28.88	49.979	65	104.3	216.753	18
	B	31.34	47.003	65	127.32	0	16
	P	14.9	17.057	65	74.49	84.918	13
6	C	23.5	45.808	65	117.49	301.364	13
	B	11.75	29.017	65	152.79	648.455	5
	P	26.23	46.529	65	106.55	235.986	16
7	C	14.88	20.152	65	80.61	153.48	12
	B	25.46	56.116	65	150.47	241.161	11
	P	14.9	29.868	65	96.85	498.746	10
8	C	14.44	24.577	65	93.84	308.134	10
	B	17.63	38.01	65	143.24	253.303	8
	P	35.58	52.711	65	96.36	142.582	24
9	C	35.68	61.984	65	105.43	207.989	22
	B	43.09	80.098	65	147.43	119.752	19
	P	30.88	61.041	65	100.37	301.133	20
10	C	25.48	30.529	65	82.79	84.439	20
	B	37.22	52.399	65	127.32	0	19

Table C-3a. Results of using 2 m radius plots and circular transects for poststratified random sampling in Paudush cutover.

Trial	Method	Sample Frame Mean pieces/ha	Sample Frame Variance of Mean	Sample Frame Sample Size	Residual Stratum Sample Frame Mean pieces/ha	Residual Stratum Sample Frame Variance of Mean	Residual Stratum Sample Frame Sample Size
	P	19.88	15.06	420	260.95	642.416	32
1	C	19.97	13.339	420	262.14	318.514	32
	B	17.05	31.692	420	795.77	0	9
	P	16.66	13.972	420	291.53	970.163	24
2	C	12.99	7.435	420	227.4	250.545	24
	B	22.74	56.342	420	954.93	11257.91	10
	P	19.88	15.06	420	260.95	642.416	32
3	C	19.97	13.339	420	262.14	318.514	32
	B	17.05	31.692	420	795.77	0	9
	P	16.66	13.972	420	291.53	970.163	24
4	C	12.99	7.435	420	227.4	250.545	24
	B	22.74	56.342	420	954.93	11257.91	10
	P	13.94	11.625	420	225.21	1244.007	26
5	C	17.17	14.532	420	267.16	1074.211	27
	B	20.84	38.547	420	795.77	0	11
	P	18.15	16.044	420	293.2	1118.066	26
6	C	15.82	10.903	420	246.06	554.215	27
	B	28.42	59.246	420	852.62	3230.905	14
	P	20.26	16.605	420	283.7	781.563	30
7	C	19.13	13.758	420	267.87	485.356	30
	B	17.05	31.692	420	795.77	0	9
	P	11.82	9.005	420	215.89	1129.115	23
8	C	13.79	9.133	420	241.34	523.843	24
	B	15.16	28.239	420	795.77	0	8
	P	19.9	17.56	420	261.22	1081.647	32
9	C	20.77	14.877	420	264.38	466.606	33
	B	32.21	65.895	420	845.51	2473.661	16
	P	16.38	16.217	420	264.64	1762.696	26
10	C	17.18	11.989	420	248.77	540.686	29
	B	24.63	52.529	420	862.09	4397.621	12

Table C-3b. Results of using 3 m radius plots and circular transects for poststratified random sampling in Paudush cutover.

Trial	Method	Sample Frame			Residual Stratum Sample Frame		
		Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
	P	21.73	29.151	186	183.74	753.677	22
1	C	20.23	26.902	186	188.12	773.774	20
	B	30.42	67.701	186	404.2	1178.222	16
	P	11.47	14.603	186	164.16	1132.328	13
2	C	10.38	10.541	186	160.86	547.353	12
	B	11.41	21.108	186	353.68	0	6
	P	16.77	20.122	186	173.34	666.457	18
3	C	13.21	11.257	186	144.53	237.936	17
	B	17.11	31.134	186	353.68	0	7
	P	19.21	18.866	186	148.89	336.571	24
4	C	23.25	28.864	186	180.22	569.434	24
	B	11.41	21.108	186	353.68	0	6
	P	17.6	18	186	155.87	397.134	21
5	C	15.92	14.207	186	140.99	282.251	21
	B	13.31	24.489	186	353.68	0	7
	P	19.93	22.145	186	154.47	476.847	24
6	C	17.41	16.21	186	154.18	273.777	21
	B	17.11	31.134	186	353.68	0	7
	P	14.11	17.74	186	154.43	889.968	17
7	C	14.01	14.753	186	173.66	436.888	15
	B	13.31	24.489	186	353.68	0	7
	P	16.91	19.86	186	184.97	569.437	17
8	C	13.02	13.019	186	151.4	470.016	16
	B	17.11	31.134	186	353.68	0	9
	P	23.01	28.604	186	203.84	500.55	21
9	C	18.8	24.068	186	184.06	731.718	19
	B	20.92	37.623	186	353.68	0	11
	P	19.88	27.939	186	194.59	922.298	19
10	C	18.58	19.602	186	181.86	322.471	19
	B	13.31	31.759	186	412.62	3474.663	6

Table C-3c. Results of using 4 m radius plots and circular transects for poststratified random sampling in Paudush cutover.

Trial	Method	Sample Frame Mean pieces/ha	Sample Frame Variance of Mean	Sample Frame Sample Size	Residual Stratum Sample Frame Mean pieces/ha	Residual Stratum Sample Frame Variance of Mean	Residual Stratum Sample Frame Sample Size
	P	12.68	16.903	105	110.98	406.692	12
1	C	12.12	14.15	105	115.66	207.082	11
	B	5.68	10.563	105	198.94	0	3
	P	8.53	10.539	105	89.59	471.931	10
2	C	11.57	13.137	105	121.5	109.857	10
	B	9.47	17.259	105	198.94	0	5
	P	19.28	21.346	105	101.22	176.919	20
3	C	23.52	29.252	105	129.99	165.122	19
	B	22.74	38.522	105	198.94	0	12
	P	15.24	23.546	105	114.31	541.704	14
4	C	11.4	14.524	105	99.73	400.658	12
	B	15.16	26.786	105	198.94	0	8
	P	19.58	20.999	105	108.18	137.988	19
5	C	19.59	20.724	105	114.26	103.195	18
	B	13.26	23.68	105	198.94	0	7
	P	14.53	15.209	105	101.73	157.27	15
6	C	17.54	23.253	105	122.79	286.131	15
	B	11.37	20.504	105	198.94	0	6
	P	11.68	13.04	105	72.15	250.84	17
7	C	15.45	13.589	105	95.4	68.839	17
	B	15.16	34.035	105	227.36	807.726	7
	P	12.8	14.854	105	89.62	280.697	15
8	C	10.73	8.826	105	86.69	69.133	13
	B	15.16	26.786	105	198.94	0	8
	P	14.85	15.674	105	103.93	153.804	15
9	C	18.29	29.932	105	128.02	552.966	15
	B	22.74	45.771	105	217.03	327.096	11
	P	23.53	30.18	105	123.52	217.231	20
10	C	18.48	20.066	105	107.78	149.848	18
	B	20.84	35.692	105	198.94	0	11

Table C-3d. Results of using 5 m radius plots and circular transects for poststratified random sampling in Paudush cutover.

Trial	Method	Sample Frame			Residual Stratum Sample Frame		
		Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
	P	7.36	8.26	67	54.76	182.824	9
1	C	12.69	19.087	67	94.48	206.289	9
	B	1.9	3.611	67	127.32	0	1
	P	20.17	29.068	67	90.09	162.104	15
2	C	14.99	16.736	67	77.26	73.463	13
	B	17.1	35.895	67	143.24	253.303	8
	P	15.79	20.822	67	75.58	158.304	14
3	C	14.32	18.882	67	87.22	123.17	11
	B	19	31.189	67	127.32	0	10
	P	14.17	21.302	67	86.32	233.57	11
4	C	10.83	13.896	67	80.64	149.714	9
	B	7.6	13.789	67	127.32	0	4
	P	19.24	23.315	67	80.58	100.074	16
5	C	14.13	16.251	67	72.84	104.337	13
	B	26.61	47.933	67	137.12	95.925	13
	P	18.37	21.16	67	76.94	89.501	16
6	C	15.98	15.358	67	71.38	40.974	15
	B	15.2	25.827	67	127.32	0	8
	P	14.98	21.777	67	91.24	179.583	11
7	C	13.73	17.872	67	91.99	78.255	10
	B	15.2	25.827	67	127.32	0	8
	P	14.28	24.064	67	95.68	317.024	10
3	C	12.25	22.634	67	91.21	489.926	9
	B	9.5	16.962	67	127.32	0	5
	P	18.09	27.301	67	93.24	189.928	13
9	C	17.45	25.723	67	106.26	90.273	11
	B	17.1	43.227	67	163.7	551.408	7
	P	19.81	27.328	67	94.83	116.828	14
10	C	10.79	11.293	67	72.31	60.602	10
	B	15.2	33.159	67	145.51	330.845	7

Table C-4a. Results of using 2 m radius plots and circular transects for poststratified random sampling in Bannerman cutover.

Trial	Method	Sample Frame			Residual Stratum Sample Frame		
		Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
	P	77.84	133.111	413	459.27	2150.505	70
1	C	74.93	94.18	413	448.49	951.712	69
	B	75.15	161.21	413	886.72	1885.329	35
	P	85.03	136.577	413	450.24	1733.906	78
2	C	85.48	102.94	413	452.61	758.36	78
	B	79	159.768	413	858.6	1244.517	38
	P	77.07	92.911	413	413.4	872.135	77
3	C	73.32	73.204	413	398.41	458.302	76
	B	77.07	149.333	413	837.66	853.383	38
	P	73.36	109.962	413	432.83	1618.949	70
4	C	75.38	85.754	413	451.21	616.046	69
	B	65.51	153.335	413	932.98	3227.063	29
	P	64.97	94.119	413	357.78	1469.866	75
5	C	74.77	81.046	413	411.72	610.614	75
	B	80.93	185.073	413	928.4	2512.956	36
	P	75.4	86.693	413	379.74	794.127	82
6	C	80.18	82.983	413	403.83	512.32	82
	B	109.83	212.628	413	855.83	849.73	53
	P	83.52	110.624	413	431.17	1080.983	80
7	C	80.36	89.045	413	420.13	628.785	79
	B	84.78	161.193	413	833.67	700.467	42
	P	98.73	115.387	413	429.22	689.526	95
8	C	91.77	91.235	413	403.19	425.667	94
	B	88.63	204.23	413	871.56	3537.359	42
	P	75.4	86.693	413	379.74	794.127	82
9	C	80.18	82.983	413	403.83	512.32	82
	B	109.83	212.628	413	855.83	849.73	53
	P	81.25	118.606	413	453.48	1423.689	74
10	C	76.45	92.02	413	438.54	826.438	72
	B	90.56	199.671	413	912.23	1977.752	71

Table C-4b. Results of using 3 m radius plots and circular transects for poststratified random sampling in Bannerman cutover.

Trial	Method	Sample Frame			Residual Stratum Sample Frame		
		Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
	P	90.53	144.785	183	271.6	497.918	61
1	C	87.46	122.629	183	285.8	295.385	56
	B	69.58	146.165	183	410.72	564.045	31
	P	76.71	118.815	183	222.83	487.948	63
2	C	85.74	118.878	183	265.95	330.716	59
	B	73.44	120.593	183	363.24	91.372	37
	P	91.7	145.226	183	254.26	491.578	66
3	C	91.39	138.884	183	283.47	413.006	59
	B	90.84	191.274	183	426.23	536.728	39
	P	76.75	149.01	183	265.02	841.303	53
4	C	61.89	94.596	183	263.41	480.733	43
	B	75.37	190.371	183	444.95	1336.353	31
	P	84.07	115.271	183	236.68	358.496	65
5	C	100.93	151.485	183	288.61	391.591	64
	B	79.24	179.577	183	426.49	842.707	34
	P	74.89	122.681	183	268.73	560.537	51
6	C	73.39	118.422	183	291.97	487.239	46
	B	67.64	181.423	183	476.1	1517.338	26
	P	77.77	140.011	183	254.14	699.094	56
7	C	79.65	125.596	183	280.29	474.605	52
	B	75.37	235.44	183	417.98	2950.594	33
	P	83.12	139.681	183	257.81	583.005	59
8	C	88.97	132.766	183	285.65	382.08	57
	B	90.84	176.252	183	405.44	390.667	41
	P	92.6	137.55	183	252.92	421.644	67
9	C	102.13	140.101	183	283.17	298.967	66
	B	98.57	205.764	183	429.47	513.676	42
	P	101.68	178.989	183	305.03	595.014	61
10	C	71.49	112.488	183	284.39	464.425	46
	B	79.24	172.065	183	426.49	619.734	34

Table C-4c. Results of using 4 m radius plots and circular transects for poststratified random sampling in Bannerman cutover.

Trial	Method	Sample Frame Mean pieces/ha	Sample Frame Variance of Mean	Sample Frame Sample Size	Residual Stratum Sample Frame Mean pieces/ha	Residual Stratum Sample Frame Variance of Mean	Residual Stratum Sample Frame Sample Size
	P	98.29	210.997	103	191.01	463.733	53
1	C	95.13	174.146	103	222.69	306.387	44
	B	110.1	239.055	103	276.58	380.246	41
	P	85.4	154.444	103	204.56	318.06	43
2	C	98.85	234.831	103	267.93	530.375	38
	B	81.12	214.257	103	288.13	642.051	29
	P	78.13	141.611	103	160.94	335.246	50
3	C	95.67	171.2	103	214.21	304.585	46
	B	79.19	168.319	103	254.9	337.884	32
	P	91.36	201.589	103	171.09	460.493	55
4	C	100.44	194.781	103	224.89	366.616	46
	B	92.71	367.799	103	280.86	1842.602	34
	P	72.91	130.184	103	163.26	332.941	46
5	C	88.2	164.917	103	221.58	317.653	41
	B	75.33	121.429	103	221.68	117.833	35
	P	85.11	144.983	103	168.59	298.414	52
6	C	78.7	151.128	103	188.51	386.273	43
	B	83.05	192.312	103	267.33	447.603	32
	P	79.68	144.031	103	186.53	336.269	44
7	C	75.37	136.035	103	204.3	304.576	38
	B	71.47	187.264	103	283.11	629.979	26
	P	76.77	125.902	103	183.89	263.379	43
8	C	66.31	120.757	103	200.88	311.55	34
	B	71.47	142.058	103	245.36	244.144	30
	P	76.71	133.549	103	154.93	307.848	51
9	C	90.79	156.24	103	212.53	265.858	44
	B	73.4	135.547	103	229.09	233.964	33
	P	72.02	101.72	103	161.27	196.433	46
10	C	81.1	164.047	103	232.03	367.257	36
	B	69.53	140.96	103	246.96	258.837	29

Table C-4d. Results of using 5 m radius plots and circular transects for poststratified random sampling in Bannerman cutover.

Trial	Method	Sample Frame Mean pieces/ha	Sample Frame Variance of Mean	Sample Frame Sample Size	Residual Stratum Sample Frame Mean pieces/ha	Residual Stratum Sample Frame Variance of Mean	Residual Stratum Sample Frame Sample Size
	P	81.25	171.575	66	134.07	290.278	40
1	C	87.14	200.186	66	174.28	338.645	33
	B	84.88	183.905	66	193.18	224.432	29
	P	93.21	182.899	66	150.04	265.245	41
2	C	95.86	268.548	66	186.09	518.032	34
	B	86.81	265.724	66	204.63	614.973	28
	P	93.98	249.976	66	167.65	462.059	37
3	C	85.46	291.641	66	208.9	790.456	27
	B	96.46	272.537	66	212.21	496.901	30
	P	78.09	198.098	66	151.58	419.845	34
4	C	83.42	260.091	66	189.86	652.414	29
	B	81.02	292.004	66	222.82	895.738	24
	P	85.27	139.949	66	134	189.391	42
5	C	82.6	146.353	66	160.34	181.883	34
	B	92.6	185.509	66	179.75	234.578	34
	P	100.15	183.581	66	157.38	237.676	42
6	C	88.32	254.893	66	194.3	546.842	30
	B	113.82	273.053	66	197.69	385.046	38
	P	119.22	238.482	66	167.42	297.803	47
7	C	124.44	283.691	66	216.14	329.946	38
	B	115.75	247.345	66	201.04	291.288	38
	P	85.27	139.949	66	134	189.391	42
8	C	82.6	146.353	66	160.34	181.883	34
	B	92.6	185.509	66	179.75	234.578	34
	P	88.75	153.587	66	124.63	207.559	47
9	C	93.45	174.881	66	176.21	201.5	35
	B	106.1	216.026	66	184.28	269.745	38
	P	100.15	183.581	66	157.38	237.676	42
10	C	88.32	254.893	66	194.3	546.842	30
	B	113.82	273.053	66	197.69	385.046	38

Table C-5a. Results of using 2 m radius plots and circular transects for poststratified random sampling in Gill-1 cutover.

Trial	Method	Sample Frame			Residual Stratum Sample Frame		
		Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
	P	95.7	135.263	413	399.24	1135.722	99
1	C	86.22	91.113	413	370.91	588.384	96
	B	79	167.211	413	881.8	1696.088	37
	P	75.09	88.299	413	352.43	839.015	88
2	C	75.87	73.094	413	360.16	471.705	87
	B	67.44	141.548	413	870.38	1735.553	32
	P	89.64	106.633	413	385.65	787.844	96
3	C	83.06	74.927	413	361.1	359.619	95
	B	94.41	227.713	413	928.4	3616.163	42
	P	92.25	116.702	413	384.86	897.658	99
4	C	90.3	100.186	413	384.47	652.553	97
	B	80.93	170.186	413	879.54	1611.945	38
	P	81.14	89.593	413	349.09	686.99	96
5	C	79.57	72.362	413	349.6	393.395	94
	B	109.83	220.072	413	855.83	1309.279	53
	P	95.05	121.384	413	388.65	903.842	101
6	C	91.05	86.147	413	372.32	404.124	101
	B	98.27	211.024	413	901.88	1663.1	45
	P	92.25	116.702	413	384.86	897.658	99
7	C	90.3	100.186	413	384.47	652.553	97
	B	80.93	170.186	413	879.54	1611.945	38
	P	81.14	89.593	413	349.09	686.99	96
8	C	79.57	72.362	413	349.6	393.395	94
	B	109.83	220.072	413	855.83	1309.279	53
	P	95.05	121.384	413	388.65	903.842	101
9	C	91.05	86.147	413	372.32	404.124	101
	B	98.27	211.024	413	901.88	1663.1	45
	P	92.25	116.702	413	384.86	897.658	99
10	C	90.3	100.186	413	384.47	652.553	97
	B	80.93	170.186	413	879.54	1611.945	38

Table C-5b. Results of using 3 m radius plots and circular transects for poststratified random sampling in Gill-1 cutover.

Trial	Method	Sample Frame Mean pieces/ha	Sample Frame Variance of Mean	Sample Frame Sample Size	Residual Stratum Sample Frame Mean pieces/ha	Residual Stratum Sample Frame Variance of Mean	Residual Stratum Sample Frame Sample Size
	P	85.07	109.654	183	225.61	312.089	69
1	C	85.93	113.089	183	241.92	315.774	65
	B	83.1	183.64	183	422.45	758.359	36
	P	87.17	134.336	183	241.69	468.386	66
2	C	85.62	129.982	183	265.56	441.235	59
	B	90.84	176.252	183	405.44	390.667	41
	P	81.77	108.825	183	241.36	326.899	62
3	C	66.65	90.242	183	225.88	371.595	54
	B	79.24	157.042	183	391.91	522.849	37
	P	105.51	152.246	183	235.46	385.655	82
4	C	109.04	161.682	183	255.83	408.906	78
	B	98.57	213.275	183	419.48	728.06	43
	P	91.88	170.033	183	271.19	700.191	62
5	C	78.6	130.55	183	248	578.19	58
	B	88.9	219.473	183	451.92	1114.099	36
	P	95.79	124.75	183	233.73	312.944	62
6	C	92.31	100.979	183	231.42	192.781	54
	B	98.57	175.718	183	392.12	269.303	37
	P	94.96	161.826	183	255.56	5730.43	68
7	C	91.51	136.368	183	253.73	425.491	66
	B	85.04	275.748	183	518.73	2798.902	30
	P	94.91	148.606	183	237.93	469.083	73
8	C	99.95	139.189	183	254.03	355.560	72
	B	73.44	173.173	183	433.54	997.926	31
	P	86.82	109.819	183	220.67	299.483	72
9	C	89.99	119.707	183	253.34	311.75	65
	B	102.43	201.495	183	407.5	479.49	46
	P	81.77	108.825	183	241.36	326.899	62
10	C	66.65	90.242	183	225.88	371.595	54
	B	79.24	157.042	183	391.91	522.849	37

Table C-5c. Results of using 4 m radius plots and circular transects for poststratified random sampling in Gill-1 cutover.

Trial	Method	Sample Frame Mean pieces/ha	Sample Frame Variance of Mean	Sample Frame Sample Size	Residual Stratum Sample Frame Mean pieces/ha	Residual Stratum Sample Frame Variance of Mean	Residual Stratum Sample Frame Sample Size
	P	113	208.741	103	204.19	354.532	57
1	C	99.29	159.011	103	200.52	249.139	51
	B	83.05	192.312	103	267.33	447.603	32
	P	98.9	210.715	103	192.2	458.398	53
2	C	101.72	157.336	103	197.68	234.975	53
	B	110.1	344.538	103	306.48	1045.599	37
	P	87.52	142.599	103	180.29	270.154	50
3	C	90.95	200.687	103	199.32	505.652	47
	B	81.12	221.791	103	288.13	739.535	29
	P	84.84	211.792	103	189.97	631.107	46
4	C	94.7	194.218	103	212.04	432.83	46
	B	84.99	343.586	103	336.67	2163.942	26
	P	93.2	207.83	103	204.25	516.826	47
5	C	93.79	194.772	103	219.56	439.379	44
	B	81.12	169.05	103	253.2	320.281	33
	P	72.45	183.497	103	177.69	663.471	42
6	C	72.7	119.25	103	187.2	253.477	40
	B	86.92	268.754	103	279.76	1105.916	32
	P	91.76	130.287	103	189.02	183.503	50
7	C	87.74	184.409	103	220.42	450.182	41
	B	73.4	150.616	103	252	266.89	30
	P	70.46	137.451	103	154.41	386.111	47
8	C	73.02	126.515	103	179.07	308.695	42
	B	63.74	137.23	103	243.15	375.865	27
	P	80.04	154.966	103	161.66	374.595	51
9	C	92.48	165.062	103	207.08	310.411	46
	B	73.4	203.358	103	260.68	887.442	29
	P	108.49	164.46	103	186.25	242.637	60
10	C	113.21	186.864	103	212.01	273.099	55
	B	98.51	187.411	103	253.65	253.075	40

Table C-5d. Results of using 5 m radius plots and circular transects for poststratified random sampling in Gill-1 cutover.

Trial	Method	Sample Frame			Residual Stratum Sample Frame		
		Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
	P	87.08	251.783	66	169.04	542.875	34
1	C	70.63	231.87	66	160.74	707.7	29
	B	92.6	344.221	66	218.27	937.393	28
	P	89.7	230.224	66	155.8	424.156	38
2	C	88.59	197.27	66	162.42	329.073	36
	B	90.67	315.651	66	221.64	812.537	27
	P	90.63	184.374	66	149.53	281.162	40
3	C	94.57	212.344	66	183.58	316.75	34
	B	86.81	250.609	66	204.63	529.198	28
	P	79.31	122.741	66	124.63	168.029	42
4	C	86.26	166.256	66	158.14	241.297	36
	B	82.95	169.992	66	161.03	269	34
	P	99.97	254.472	66	160.92	420.439	41
5	C	90.76	249.046	66	187.2	494.688	32
	B	104.17	339.412	66	214.86	700.669	32
	P	69.43	101.713	66	127.3	135.861	36
6	C	67.94	141.648	66	140.12	286.32	32
	B	67.52	137.7	66	171.4	196.647	26
	P	82.33	153.767	66	135.84	236.464	40
7	C	101.97	276.832	66	181.9	487.763	37
	B	77.17	188.028	66	188.63	340.41	27
	P	92.04	170.168	66	138.07	238.077	44
8	C	86.76	147.336	66	146.83	194.396	39
	B	100.32	245.742	66	206.9	351.356	32
	P	116.79	290.108	66	179.25	422.52	43
9	C	110.07	275.602	66	186.27	424.278	39
	B	108.03	304.142	66	209.71	516.752	34
	P	77.28	161.743	66	130.79	284.061	39
10	C	76.41	133.216	66	148.33	186.099	34
	B	79.1	194.727	66	193.34	340.41	27

Table C-6a. Results of using 2 m radius plots and circular transects for poststratified random sampling in Gill-2 cutover.

Trial	Method	Sample Frame Mean pieces/ha	Sample Frame Variance of Mean	Sample Frame Sample Size	Residual Stratum Sample Frame Mean pieces/ha	Residual Stratum Sample Frame Variance of Mean	Residual Stratum Sample Frame Sample Size
	P	90.1	111.594	407	412.01	847.246	89
1	C	92.08	110.127	407	435.79	727.248	86
	B	93.85	208.244	407	909.46	1891.261	42
	P	72.24	92.203	407	408.38	1047.006	72
2	C	73.36	90.96	407	414.68	946.753	72
	B	62.57	166.644	407	979.42	6444.984	26
	P	66.05	84.127	407	378.64	1106.194	71
3	C	74.17	82.943	407	419.28	643.072	72
	B	62.57	128.321	407	848.83	1358.713	30
	P	77.88	108.082	407	401.22	1235.151	79
4	C	75.69	88.481	407	405.34	783.424	76
	B	76.25	158.132	407	862.09	1382.109	36
	P	85.49	97.51	407	386.62	703.5	90
5	C	85.2	91.138	407	398.56	560.575	87
	B	99.72	247.603	407	966.3	3335.974	42
	P	84.68	116.775	407	430.79	1165.774	80
6	C	84.27	98.142	407	434.13	684.517	79
	B	80.16	179.619	407	881.8	2646.924	37
	P	77.09	112.656	407	418.35	1424.856	75
7	C	80.36	106.636	407	441.97	1072.532	74
	B	78.21	176.549	407	909.46	2280.639	35
	P	78.87	92.767	407	368.98	904.095	87
8	C	88.27	93.454	407	417.73	493.342	86
	B	66.48	173.067	407	966.3	5624.168	28
	P	73.04	91.281	407	386.06	2645.541	77
9	C	70.86	64.206	407	374.54	316.407	77
	B	80.16	187.283	407	932.19	987.410	35
	P	76.9	99.27	407	372.62	1025.189	84
10	C	81.3	88.109	407	403.98	583.159	82
	B	93.85	223.573	407	909.46	3362.243	42

Table C-6b. Results of using 3 m radius plots and circular transects for poststratified random sampling in Gill-2 cutover.

Trial	Method	Sample Frame			Residual Stratum Sample Frame		
		Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
	P	95.07	190.097	181	268.88	794.246	64
1	C	80.95	122.56	181	252.6	447.072	58
	B	89.88	208.516	181	428.14	917.767	38
	P	99.09	178.137	181	252.6	613.787	71
2	C	92.03	136.868	181	268.67	401.061	62
	B	115.29	290.904	181	463.71	1114.7	45
	P	72.02	111.247	181	232.79	496.32	56
3	C	69.43	103.81	181	256.45	438.733	49
	B	58.62	103.77	181	365.87	148.737	29
	P	76.68	104.117	181	247.83	330.101	56
4	C	67.92	81.088	181	245.87	185.409	50
	B	68.39	146.788	181	399.31	737.597	31
	P	94.95	161.272	181	277.2	561.095	62
5	C	88.42	133.38	181	275.93	406.748	58
	B	105.52	260.656	181	465.82	982.248	41
	P	61.84	108.757	181	211.18	679.169	53
6	C	69.66	117.825	181	257.32	626.084	49
	B	68.39	185.183	181	458.47	1715.882	27
	P	75.68	117.247	181	240.33	490.126	57
7	C	79.11	129.028	181	280.76	516.224	51
	B	76.21	232.655	181	459.78	2631.159	30
	P	83.85	120.355	181	237.15	395.468	64
8	C	87.88	122.641	181	260.75	340.455	61
	B	89.88	246.91	181	478.51	1534.579	34
	P	64.57	87.877	181	216.42	380.276	54
9	C	74.66	101.545	181	259.88	303.652	52
	B	78.16	150.352	181	392.98	352.982	36
	P	67.03	91.713	181	212.84	381.921	57
10	C	80.31	117.472	181	285.01	333.992	51
	B	74.25	122.946	181	363.24	91.372	37

Table C-6c. Results of using 4 m radius plots and circular transects for poststratified random sampling in Gill-2 cutover.

Trial	Method	Sample Frame Mean pieces/ha	Sample Frame Variance of Mean	Sample Frame Sample Size	Residual Stratum Sample Frame Mean pieces/ha	Residual Stratum Sample Frame Variance of Mean	Residual Stratum Sample Frame Sample Size
	P	90.57	163.564	101	198.86	319.498	46
1	C	86.82	188.3	101	230.75	455.043	38
	B	94.55	255.451	101	289.37	681.449	33
	P	66.29	101.212	101	148.77	237.369	45
2	C	67.8	101.539	101	171.21	203.482	40
	B	74.85	147.745	101	243.87	230.635	31
	P	78.72	124.922	101	180.7	238.316	44
3	C	90.58	186.157	101	228.71	395.161	40
	B	66.97	151.082	101	241.57	456.216	28
	P	71.99	150.708	101	177.35	461.019	41
4	C	66.88	110.476	101	173.2	268.305	39
	B	68.94	191.511	101	290.13	714.016	24
	P	64.93	97.851	101	156.14	226.552	42
5	C	63.37	107.183	101	177.79	277.941	36
	B	61.06	154.729	101	256.97	642.316	24
	P	94.74	141.083	101	173.97	224.515	55
6	C	97.66	164.181	101	209.86	255.084	47
	B	74.85	155.583	101	252	266.89	30
	P	67.91	88.828	101	134.48	172.77	51
7	C	75.13	145.724	101	180.68	389.587	42
	B	70.91	129.976	101	231.03	178.467	31
	P	75.65	101.837	101	159.17	173.037	48
8	C	81.08	135.883	101	190.44	264.069	43
	B	70.91	137.813	101	238.73	218.365	30
	P	71.26	130.594	101	175.54	346.649	41
9	C	60.52	120.668	101	197.19	412.178	31
	B	72.88	162.411	101	253.82	379.852	29
	P	68.7	111.743	101	157.7	270.101	44
10	C	64.38	100.371	101	175.73	217.514	37
	B	68.94	120.975	101	224.61	148.265	31

Table C-6d. Results of using 5 m radius plots and circular transects for poststratified random sampling in Gill-2 cutover.

Trial	Method	Sample Frame			Residual Stratum Sample Frame		
		Mean pieces/ha	Variance of Mean	Sample Size	Mean pieces/ha	Variance of Mean	Sample Size
	P	81.51	140.389	65	143.2	193.092	37
1	C	80.93	220.274	65	187.87	467.982	28
	B	76.39	162.114	65	183.91	200.141	27
	P	87.79	221.289	65	172.91	411.777	33
2	C	75.56	291.33	65	181.92	982.29	27
	B	76.39	193.29	65	198.63	328.551	25
	P	52.65	85.156	65	118.02	160.765	29
3	C	81.63	191.182	65	182.96	317.341	29
	B	54.85	124.463	65	178.25	204.775	20
	P	81.54	148.842	65	139.47	222.012	38
4	C	84.69	236.273	65	172.04	506.119	32
	B	56.81	132.737	65	167.84	307.831	22
	P	93.28	204.854	65	155.46	320.623	39
5	C	76	204.626	65	176.43	469.77	28
	B	95.98	288.615	65	207.96	577.026	30
	P	78.53	148.375	65	127.61	235.068	40
6	C	81.7	150.705	65	147.52	220.158	36
	B	74.44	178.421	65	186.09	310.798	26
	P	82.05	168.228	65	140.35	276.588	38
7	C	77.63	118.951	65	152.92	108.856	33
	B	88.15	248.806	65	197.57	502.561	29
	P	68.79	134.01	65	139.73	242.212	32
8	C	65.1	118.542	65	145.92	186.123	29
	B	78.35	200.244	65	203.72	324.228	25
	P	58.29	112.431	65	118.4	241.909	32
9	C	70.08	158.798	65	168.7	301.088	27
	B	47.01	82.376	65	145.51	99.253	21
	P	100.51	197.29	65	151.93	268.422	43
10	C	102.07	240.561	65	184.29	361.292	36
	B	95.98	187.294	65	183.5	207.806	34