The Effects of Clumped Log Distribution on Line Intersect Sampling

A dissertation submitted in partial fulfilment of the requirements for the degree of Bachelor of Forestry Science with Honours by:

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1.0 Abstract

Line intersect sampling (LIS) is a method used for quantifying post-harvest waste. It is often used by forest managers to quantify merchantable volume remaining on the cutover so that compensation may be exacted under stumpage contracts.

The theory has been extensively studied and will produce an accurate measure of harvest waste given the basic theoretical assumptions that: all logs are cylindrical, occur horizontally, are randomly orientated and randomly distributed. When these assumptions are violated, the method is not biased, although precision decreases substantially.

A computer simulation was completed to determine whether or not the LIS method is appropriate, given a clumped distribution of logs produced by processing at central sites in cutover before using a forwarder to extract to the landing. The software ArcGIS with the application ModelBuilder was used to produce the LIS Model for running LIS assessments.

It was determined through simulation that the conventional LIS method is not appropriate given these harvesting methods, as a level of bias was found in sampling determining that the LIS method underestimated true volume. T-tests confirmed the significance of this bias.

LIS volume estimates were not precise, with the range of estimates ranging from 0 m^3/ha to double the true volume. An increase in sampling length by a third was found to increase precision by only a small amount. Therefore, it was determine that increased sampling is not worthwhile as the costs associated with it do not justify the small increase in precision

Contents

2.0 Acknowledgements

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3.0 Introduction

Since its initial development by Warren and Olsen (1964), the line intersect sampling (LIS) method for assessing logging waste has been extensively studied and is well proven. It is often used by forest managers to quantify merchantable volume remaining on the cutover so that compensation may be exacted under stumpage contracts.

LIS has been studied through simulation methods, with adjustments being made to correct for the main potential sources of bias: non-random log orientation, log tilt from horizontal plane and non-circular log cross section (Wagner, 1982). However, there is an apparent gap in the research relating to another source of bias, non-random distribution of logs by means of clumping.

Matariki Forests, managed by Rayonier New Zealand limited, is the owner a considerable forest estate across the Southland and Canterbury regions of New Zealand. Harvesting methods of crews across this estate cause orientation bias and a clumped distribution of logs by processing tree stems at multiple in-forest processing sites, before forwarding to the main landing.

This dissertation examines the appropriateness of the LIS method for assessing logging waste, given clumped distribution of logs throughout the cutover under orientation bias.

4.0 Literature Review and Background

4.1 Introduction

Post-harvest sampling of merchantable waste is sometimes necessary under stumpage contracts to quantify a compensation payment made by the stumpage customer, given that there is an excessive volume of merchantable waste remaining on the cutover. There is an extensive range of studies that investigate the appropriateness of the LIS method as a tool for assessing merchantable logging waste. Under the basic theoretical assumptions that all logs are cylindrical, occur horizontally and are randomly orientated, LIS is proven to be a very effective method, producing accurate and precise estimations (Van Wagner, 1982).

Reviewed studies have largely focused on the effectiveness of the LIS method when the basic assumptions have been violated. These studies have determined that violation of the basic assumptions can result in a lack of sampling precision and in some cases, induce bias to the sampling estimates (Bell et al, 1996). As a result, the LIS methodology has been adjusted multiple times to increase accuracy and precision of sample estimates.

4.2 The LIS Method

The LIS method was first developed by Warren and Olsen (1964) after a determination was made that simple area plots were not cost effective, and introduced bias into post-harvest sampling of waste. The method described used a line of known length to intersect logs in a cutover, with the diameter of the log recorded at the point of intersection.

Van Wagner (1968) further developed the method determined by Warren and Olsen to produce the equation that is used today to determine wood volume per unit area (m^3/ha):

$$V = \left(\frac{\pi^2}{8L}\right)\sum_i d_i^2$$

Where: V is the volume of wood (m^3/ha), d is the log diameter at the point of intersection and L is the length of sample line used. The function $\pi^2/8$ is the addition of two factors: π/2 and π/4 where π/2 is a probability theory factor allowing the cross sectional area of intersection to be summed elliptically and π/4 is a factor used to transform d^2 into a circular area (Van Wagner, 1982). Using this equation with the basic assumptions that all pieces are cylindrical, occur horizontally and are randomly orientated, volume (m^3/ha) is accurately predicted.

4.2.1 Sources of bias in LIS

Horizontal Tilt

If a piece is tilted from horizontal (tilted from the ground plane), the probably of that piece being intersected by the sample line decreases (Brown & Roussopoulos, 1974). Van Wagner (1982) considered the effect of non-horizontal pieces on the LIS method and determined a correction factor of 1/COS×h, where h is the angle of tilt away from the horizontal. It was determined that the error induced by tilted pieces can be very minimal, and therefore, whether or not to correct for tilt is a decision to be made at the individual survey level, based on observations of tilt. With respect to ground slope, Brown (1974) provides a correction factor for slope tilt where the LIS result is multiplied by:

$$\sqrt{[1 + (\frac{percent\ slope}{100})^2]}$$

Non-Cylindrical Pieces

The effect of non-cylindrical pieces due to tree taper is analysed in Pickford and Hazard (1978). It was concluded that non-cylindrical pieces did not induce bias to the sample, although they decreased precision of sampling. The result of this was an increase in sampling intensity to increase precision. Van Wagner (1982) suggested that bias could be introduced by sampling with only one diameter measurement, as a log piece will not always be perfectly circular. Therefore, two measurements should always be taken to represent the cross sectional area of the merchantable log piece.

Bate et al (2009) estimated log characteristics using LIS. The study indicated that for a more precise and unbiased estimate of volume, logs should be measured at the LED as well as the intersecting point.

Non-Random Orientation

The sample layout configuration used in LIS sampling has been extensively reviewed concerning how the transects are laid out to remove bias from the sample. The most unbiased LIS layout has been determined as an equilateral triangle with 25m long sections (Bell et al, 1996; Van Wagner, 1968). However, an alternative LIS lay-out consisting of a transect with two 25m segments at right angles to each other described by Sutherland (1986) is found to be almost as accurate as the equilateral triangle (Bailey, 1970 ; Bell et al, 1996). Linnel Nemec and Davis (2002) have described how the right angle layout is 50% faster to install than the equilateral triangle, making it the most practical option ; which leads to it being industry standard in New Zealand (Herries, 2013).

Bell et al (1996) determined that non-random orientation resulted in decreased precision of LIS assessments. This study examined the effects of orientation bias whereby logs are orientated about a mean log orientation with a truncated normal distribution. Although no sampling bias was found to occur because of log orientation bias, precision was decreased to a level where any single LIS assessment is worthless; a conclusion also determined by Van Wagner (1982).

Non-random distribution

There is a lack of literature that examining the effects of non-randomly distributed logs throughout the cutover. However, O'Hehir & Leech (1997) determined that non-random distribution of logs would likely result in a biased estimate of volume, and therefore, suggested that the method may need modification. Pickford and Hazard (1986) examined the effects of non-random distribution caused by harvesting using cable logging systems and determined no sampling bias occurred when using right angle segments.

De Vries (1973) determined that for LIS to produce and unbiased estimate of volume, the residue pieces must be randomly distributed over the area. Howard and Ward (1972) concluded that the perpendicular lines significantly reduce bias cause by clumped log orientation. Therefore, the literature is conflicting.

4.3 Accuracy and Precision

The precision of individual LIS is typically measured using the standard error of individual line segments (Van Wagner, 1982). The standard error is calculated using the following equation: $\frac{s}{x} = s/\sqrt{n}$

Where: $\frac{s}{x}$ is the standard error in units of m^3/ha, n is the number of individual 50m sections in the total sample, and s is the standard deviation based on individual section volumes. The standard error is a good measure of precision for individual LIS assessments as it provides a range for which the true volume should lie.

Peter Hall (1996) determined accuracy and precision of LIS assessments by calculating the percentage mean absolute error and the 95% confidence limits ; this was given a known volume per area unit (m^3/ha). The percentage mean absolute error is calculated as the percentage difference in the LIS estimate of volume to the true volume, and is determined to be significant by use of a t-test. Bell et al (1996) used a similar method, calculating the standard deviation of the percentage absolute error. However, the method in Bell et al (1996) differed from the method of Peter Hall (1996) as it was calculated in terms of a value that represented both length of sampling line and the number of logs in the stand ; length multiplied by density.

The standard error, and therefore precision, is dependent on the length of sampling and the density of merchantable waste on the cutover (Warren & Olsen, 1964). Pickford and Hazard (1978) determined that increasing precision by a factor of two would require four times the sampling. G. Woldendrop et al (2004) concluded that spatial distribution, log frequency and log size all had significant influence on precision of LIS log estimates. Therefore, the length of sampling used should be determined as a combination of the estimated volume remaining on site, as well as the sampling precision required. Economics of the assessment should also be considered when deciding the length of sampling to use, as an increase in precision will mean an increase in the cost of assessment.

4.4 LIS by Simulation

Simulation studies of LIS were first used by Pickford and Hazard (1978) because of the determination that obtaining enough samples to thoroughly assess the statistical properties of the method is very impractical and costly. Bell et al (1996) noted that stands could be modelled exactly using computer simulation, with particular volumes based on distributions of log lengths and diameters. In this way, computer modelled iterative LIS assessments can be completed in a comparatively short time to practical LIS assessments.

The number of required simulations for given parameters is not entirely obvious. Pickford and Hazard (1978) choose to iterate their simulation 1,500 times for each population; a value determined by prior trialling. This was despite determining that within 700 iterations, the expected values of residue volume (absolute error) and sample variance stabilised. Bell et al (1996) used typically 10,000 iterations of each population, while Pickford and Hazard (1986) used 2,000 iterations for each population. In order to complete such a large number of iterations, each study used purpose built computer models.

One of the advantages of using a simulation approach is that potential forms of bias can be removed or added to the sampling, depending on what is being tested. This was demonstrated in Bell et al (1996) as the study induced controlled orientation bias into a simulated stand.

4.5 Contractual Requirements of Rayonier/Matariki Forests

Under the Rayonier/Matariki forests stumpage contract there is a number of specific requirements that the stumpage customer must adhere to, or be penalised. The contract requires 100% of the merchantable volume in the cutover be extracted in the year that the stand is tendered for. Any volume remaining after this time period may be charged out at double the normal rate to the customer. Therefore there is the incentive for Rayonier to quantify the remaining merchantable volume. Table 1 displays the minimum size and quality requirements for merchantable volume. Regardless of quality, all remaining volume is determined by the minimum requirements of the pulp grade.

Table 1: Merchantable volume requirements

Log Grade	Length	Small end diameter	Large end diameter	Sweep	Comment
Pulp	≥3m	≥10cm	-	≤SED/1	No rot, insect damage or internal shatter

4.6 Notes on practicality of LIS

Interpine Forestry is one of New Zealand's specialist forest mensuration companies. They carry out between 1500-1700m (30-34 line segments) of sampling in LIS assessments, regardless of cutover size (Herries, 2013). This length of sampling is determined as a balance of expected precision of the LIS volume estimate and the assessment costs. An LIS assessment of 30-34 line segments will cost a forest manager between \$800 and \$900 based on each line segment costing between \$26 to 27. Therefore, unnecessary precision through the use of extra line segments carries an undesirable cost.

Interpine forestry currently does not have any operational methodology in place to deal with areas of known distributional bias in the cutover. The exception is the methodology that is in place to deal with main landings. Under this methodology, any sampling segment that tracks towards a landing will be re-directed at a right angle at the point of intersection with the landing. This ensures that forms of log bias present on the landing are not included in the sample.

5.0 Problem Statement

The Rayonier/Matariki Forests Southland stumpage sales contract requires that 100% of merchantable volume is removed from the cutover; a level of discretion is determined on a case by case basis by the staff. When remaining merchantable volume is observed to be high, line intersect sampling (LIS) is used to quantify the volume. A recent LIS assessment of merchantable volume left on the cutover estimated an unrealistic volume. The cutover was subsequently enumerated using unconventional methods, concluding a volume less than half of that determined by the LIS assessment. Therefore, negotiations and resulting compensation for the excess remaining volume with the customers was difficult. This has not been an isolated case.

The suggestion has been made, both by the stumpage customers and Rayonier staff, that the harvesting method of several crews operating in the Matariki Southland forest estate causes distributional bias of merchantable log pieces. The harvesting method involves shovelling to multiple in-forest processing sites, before using a forwarder to extract to the main landing

5.1 Primary Question

Given areas of clumped merchantable pieces under orientation bias left on site, is the LIS method appropriate?

5.2 Secondary Question

How does the precision of estimates change with increased sampling?

6.0 Methods

A simulation approach was chosen for this study, as a stand with a particular volume, based on corresponding log lengths and diameters could be modelled reasonably simply with computer simulation (Bell et al, 1996). The program ArcGIS was chosen as the medium for which to run computer simulations of LIS assessments, with the application ModelBuilder providing the platform to do so. A Model has been produced using ModelBuilder aptly named the LIS Model.

6.1 A Brief Detailing of the LIS Model

The LIS model in ModelBuilder essentially creates line features that represent logs throughout a simulated cutover; this is based on a number of set parameters. They are created from random point locations in both the cutover and in-forest processing sites. The line features are based on a set length at a specified orientation from the large end diameter (LED) to the small end diameter (SED), and unlike real logs, are defined as infinitesimally small in width. The values for LED and SED are located in the attribute table associated with each respective feature.

The LIS Model also creates systematic sampling line segments as line features in the cutover. At the points where log features are intersected by the sample lines, the log features are split in two, with the split log feature containing the original LED being selected for further analysis. The diameter of intersection is determined used basic trigonometry assuming normal taper of logs.

6.2 Verification of Inputs

Verification of the inputs of the model was seen as necessary to keep the project specific to the Matariki forest situation and the problem at hand. In particular, defining the distribution of merchantable log length, LED, SED and orientation was necessary as they are influenced by the contractual requirements of Rayonier. The verification of inputs is in contrast to previous studies, such as Bell et al (1996) who simply fitted a weibull distribution to log length, SED and LED while orientation was defined as being normally distributed about a mean orientation angle. In order to verify the input variables for the model, field testing was undertaken in the Matariki forest estate in Canterbury, New Zealand.

6.2.1 Choice of sites for field testing

Two cutovers were chosen in Ashley forest to complete field verification. The sites were chosen based on the harvesting method, where trees were extracted to multiple in-forest processing sites, processed and subsequently extracted to the main landing using a forwarder. This formed a clumped distribution of merchantable pieces remaining on site. Harvesting of these particular cutovers, named Makerikeri road and Ngaumu road respectively, had concluded within two weeks of the field testing occurring; this ensured that all merchantable material was obvious. The total area of each cutovers was approximately 10 ha.

6.2.2 Field measurements taken

Log size distributions

It was important that through field testing, the distributions of size and orientation of merchantable pieces remaining on site were determined. To collect an unbiased sample of these variables, LIS type samples were laid over the cutover (excluding in-forest processing sites) to randomly select logs to be measured in an efficient manner. Intersecting logs had their length, LED, SED and orientation (from the LED) recorded. Special care was taken to ensure that where possible, LED and SED measurements were taken as a cross sectional measurement, to correct for noncircular shape.

In forest processing sites

In forest processing sites were completely enumerated, with measurements of length, LED, SED and orientation taken for each log. A GPS mark-up of the processing site boundary was taken to provide an indication of the size distribution of such sites. Care was taken to include all the different areas encapsulated in the processing site, including: forwarder tracks, slash piles, log piles and any area that visually looked as though it had been used for processing of logs; discretion was applied. Four processing sites at Makerikeri road and two at Ngaumu road were measured. The Ngaumu road cutover contained less processing sites, as about half of the cutover was harvested using alternative methods because of steep terrain.

6.2.3 Interpretation of Field Measurements as Stand Variables

The distributions of log length, LED and SED were all analysed and subsequently edited to remove inconsistencies that result from a relatively small sample size. A total of 118 different logs were measured throughout the two cutovers, with no obvious difference in log sizes found between the in-forest processing sites and the remaining cutovers; 66 logs were located on in-forest processing sites with the other 52 scattered throughout the cutover.

In-Forest Processing Sites

The in-forest processing sites ranged in size from 700 m^2 to 1400 m^2; with an average size of 1042 m^2. Therefore, 1000 m^2 was chosen to be the modelled area for simulation of LIS assessments as this value conveniently represents exactly 0.1 ha. It was determined that each processing area serviced an average area of 2.5 ha. This value is based on the assumption that half (5 ha) of the Ngaumu road cutover was not harvested using the methods that produce distributional bias.

The location of the in-forest processing sites is practically determined by the lay of the land as well as stand geometry. However, the location is not always entirely obvious, as is the case for the Makerikeri cutover (Figure 1); this makes it very hard to replicate through simulation. Therefore, the assumption is made that the processing sites are distributed with partial randomness, with the constraint that processing sites may not be located within 50 m of the edge of another processing area. Although the smallest distance that a single processing area was located from another was 35 m (Figure 1), it is more appropriate to used 50m, as the processing sites were generally located greater than 50m apart.

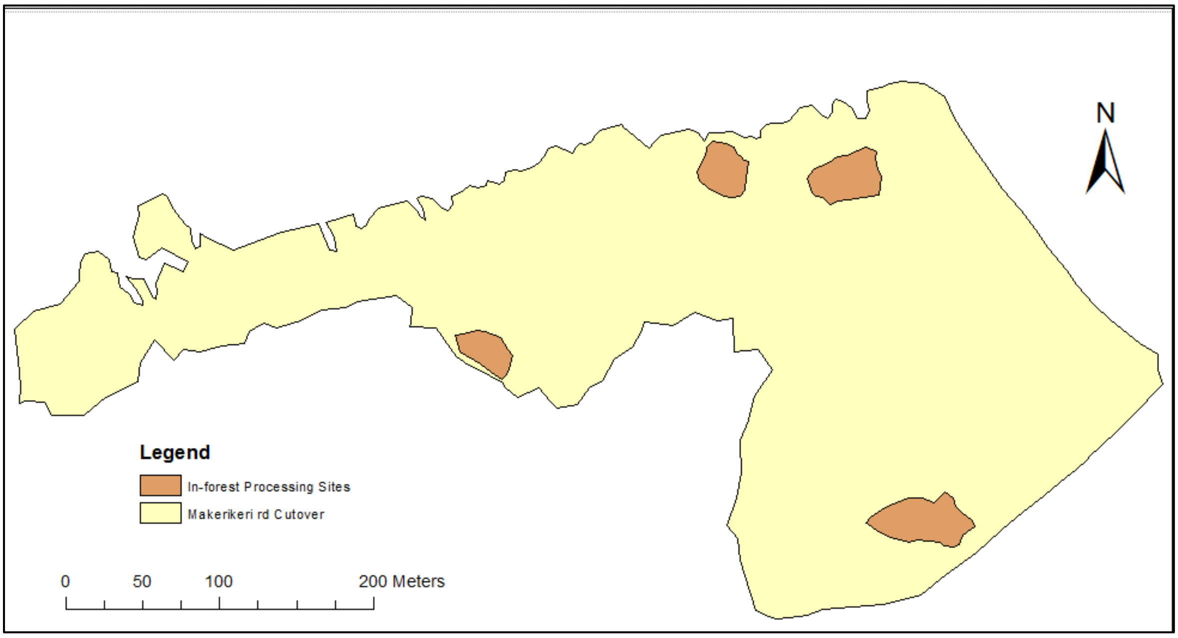

Figure 1: Map of Makerikeri Rd cutover with in-forest processing sites

Log Length

The distribution for length, LED and SED was categorised based on different size classes, given the proportion of different sizes. The original dataset was then sized up slightly to 120 as the distribution was edited to be slightly smoothed; gaps were filled while the proportion of larger logs making up the tail end of the distribution was increased. A further 1,920 values were added, making a total of 2,040 log lengths. Using a random number generator, a number between zero and one was added to the base categorical value of length for each size class of these extra values; this was based on the proportions from the initial dataset of 120. The resulting length distribution is displayed in Figure 1.

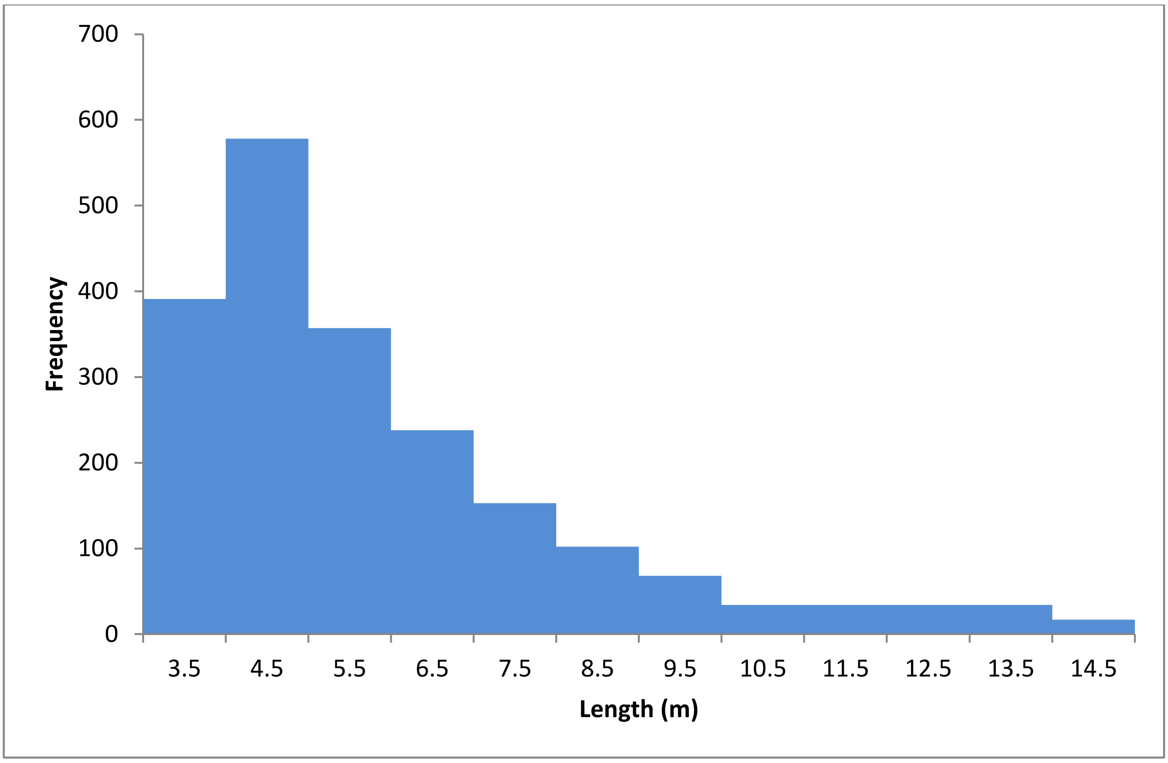

Figure 2: Distribution of length values

LED

The distribution for LED is almost exactly representative of the 119 original measured values. However, the distribution has been slightly smoothed in places to better represent missing diameter classes. The distribution was exactly replicated from 120 values to 2040 values to match with the length distribution values (Figure 2). This gives a large dataset from which to choose representative LED measurements for simulation. The distribution of LEDs shows that the majority of logs sampled are small in diameter, with logs of LED exceeding 400mm relatively uncommon

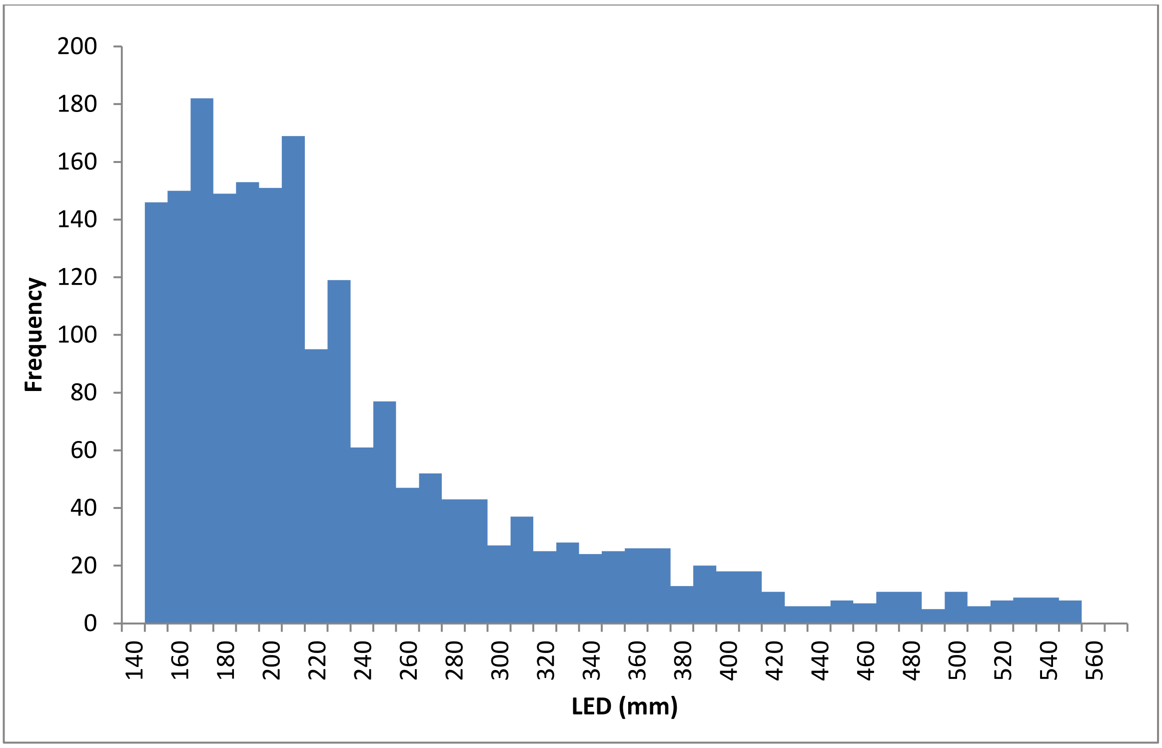

Figure 3: Distribution of LED values

SED

Field testing determined there is a moderate positive relationship (R^2 = 0.6476) between LED and SED, as displayed in Figure 4. It was decided that the SED values used in the simulated cutovers would be determined by the LED values using the linear regression:

$$SED = 0.7098 \times LED - 2.2852$$

This keeps the SED values very simple, as they correspond directly to the LED values. Normal taper can be assumed for the log pieces.

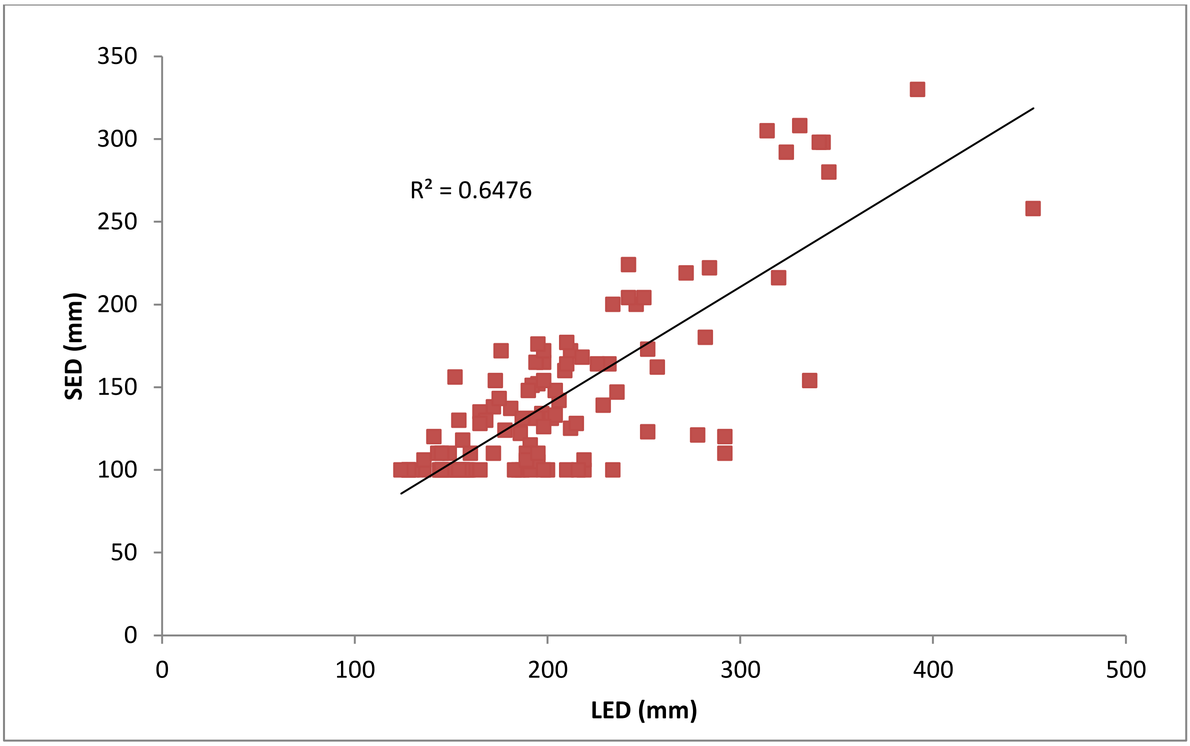

Figure 4: Relationship between LED and SED

Orientation

Orientation bias was only found to occur in the in-forest processing sites, and therefore, was only analysed for these sites. The numbers were first modified to look at orientation within the restrictions of 180^{o}, removing the fact that orientation was measured from the LED as a 360^{o} measurement. This allowed the mean orientation angle to be calculated for each in-forest processing area, with the actual orientation angle of each log being subtracted from the mean orientation angle to determine a distribution of values about the mean.

Although the orientations were found to be distributed about a mean value of zero degrees, they followed a relatively even distribution with maximum deviation of 42^{o} each side of the mean. Therefore, a random number generator could be used to create numbers representing an even distribution either side of the mean, giving a range from 0^{o} to 84^{o} of orientation for 1020 log pieces. The remaining 1020 log pieces were assigned an orientation angle between 222^{o} and 306^{o}, representing a 180 degree difference in orientation from the other pieces. This helped to represent the fact that the LED of log pieces was typically orientated within the same range even if the log was facing the opposite direction.

6.2.4 Use of Stand Variables

In-Forest Processing Sites

All simulations occurred based on a purpose simulated 20 ha rectangle shaped cutover. This was a reasonable assumption as all variables are measured on the unit basis of m^3/ha. The cutover contains eight in-forest processing sites that are located with a partially random distribution throughout the cutover. Partially randomised location of processing sites was achieved by creating randomly located polygon features with a constraint that all processing sites may not be within 50 m of each other, based on the results of field testing. The in-forest processing sites were created as circular features.

Length, LED and SED

Length and LED were randomly selected from the 2040 values for each log. This was possible as it was assumed that length and LED were independent from each other based on the relationship in Figure 5. This determination was supported by the representation of a very similar relationship when the selected lengths and LEDs were trial graphed against each other. The values for length, LED and SED were all identified under individual log piece IDs, ranging from 1-2040.

The volume of individual logs was calculated using Smalians formula with the variables of length, LED and SED for each log as described in Patterson & Doruska (2002). Volume was then calculated as a per hectare value. This meant that choosing specific volumes was simplified, as the number of log pieces that equalled the specified volume per hectare was selected, then subsequently used as the dataset of log pieces.

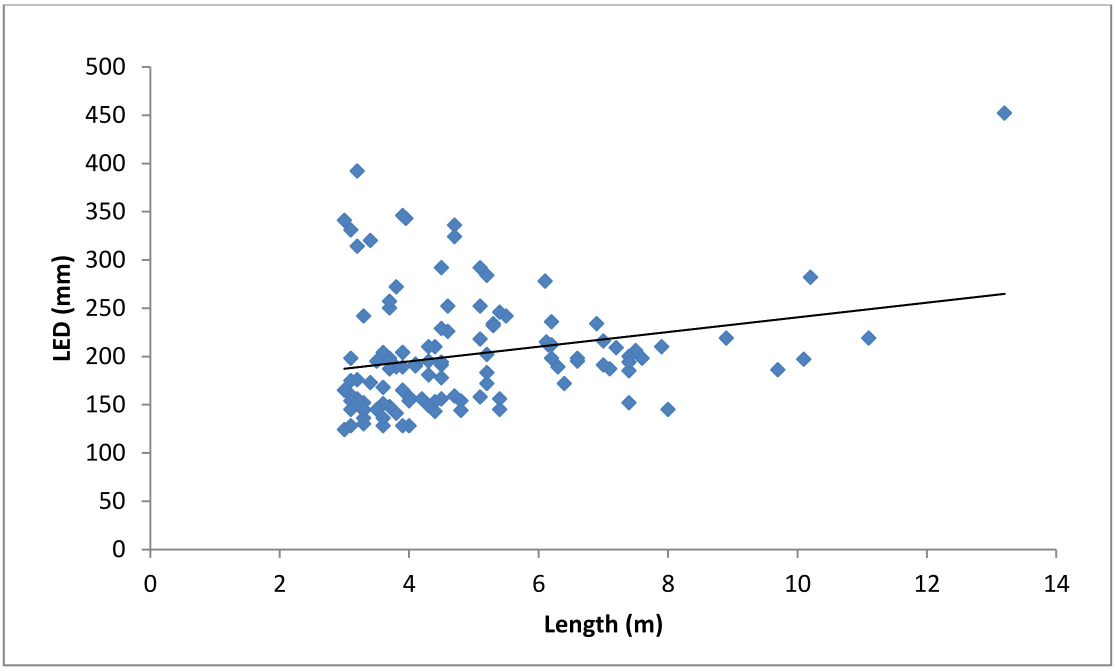

Figure 5: Relationship between length and LED based on field measurements

6.3 LIS Simulation

6.3.1 LIS with Random Log Distribution

A simulation was initially completed to determine the accuracy, precision and therefore the appropriateness of using the LIS model. This simulation was kept basic, using 1,500m of sampling (30 line segments) and volumes per ha of 2 m^3, 4 m^3, 6 m^3 and 8 m^3 respectively. It should be emphasised that this testing was purely to determine whether or not the model, with given parameters, produced any bias in the LIS estimates. An example of a cutover with 8m^2/ha is displayed in Figure 6; logs are represented as brown features and line segments as black features at right angles.

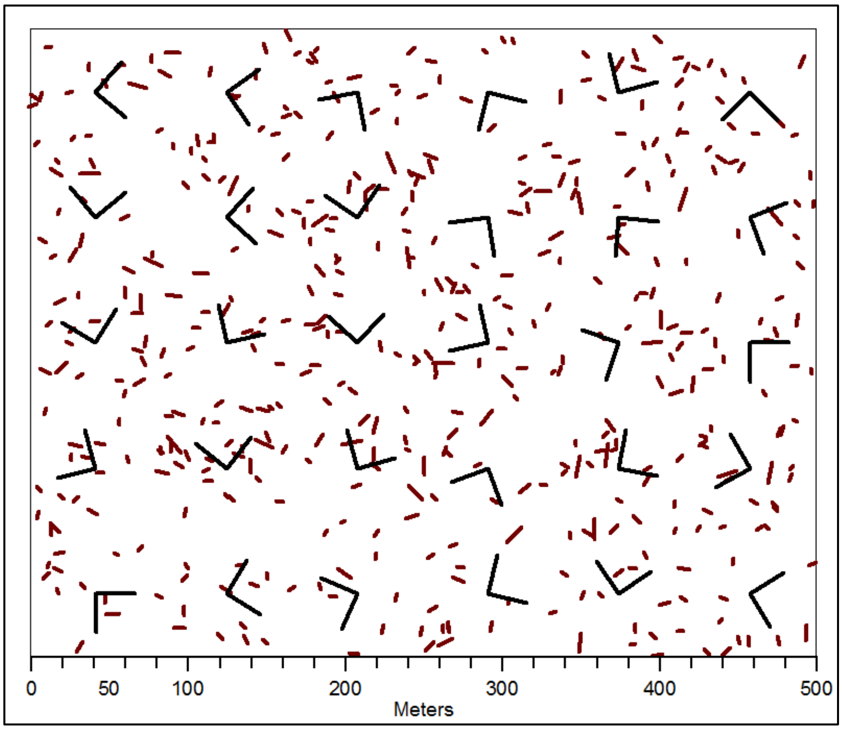

Figure 6: Random log distribution at 8 m3/ha true volume

6.3.2 Base Sampling Intensity

A base sampling intensity was chosen based on the standard operating procedure of Interpine Forestry. The base intensity involved using a total of 1,500 m of sampling, or 30 individual 50 m right angle line segments. The line segments are arranged in a systematic grid pattern, with the first section of right angled segment orientated on a randomly chosen angle.

The type of sampling and clumped distribution of logs is displayed in Figure 7. The logs are represented by brown line features, while the line segments are represented by the black line features are right angles. It should be noted that the true volume is 8 m^3/ha, with 7 m^3/ha of this volume located in the processing sites represented as large clumping of log features.

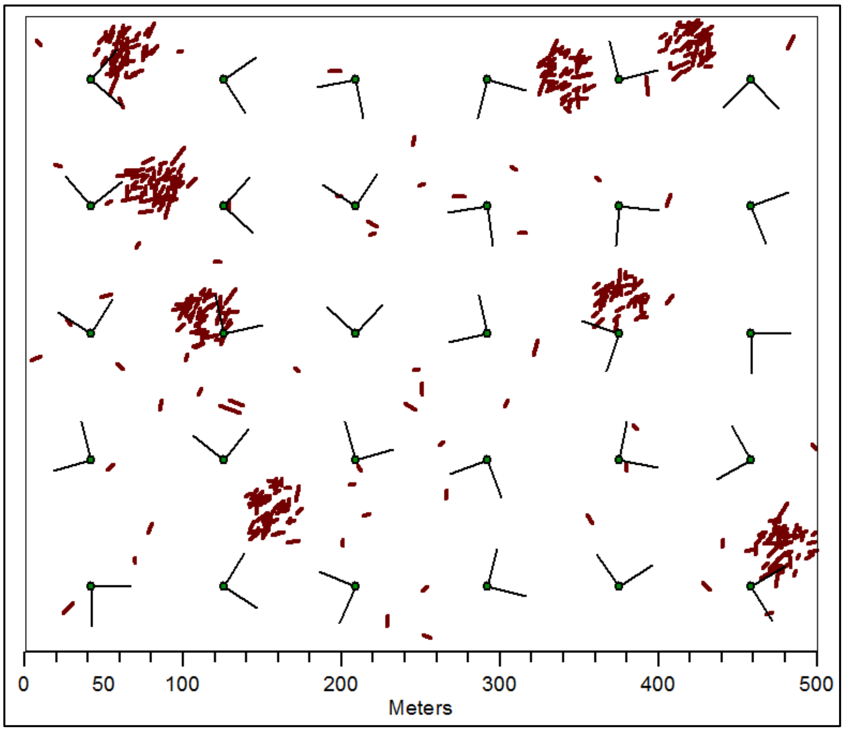

Figure 7: Clumped log distribution at 7 m3/ha true volume

6.3.3 Volumes

Volumes are determined on a per hectare basis. However, they are split into volume for the cutover and volume for the in-forest processing sites. It should be noted that processing area volumes were quoted in terms of m^3/ha for the entire 20 ha stand, and not scaled to the 0.8 ha that they represent. This means that the cutover volume and processing area volumes are both quoted in like terms, resulting in consistency across the stand. The volumes used for the initial runs are displayed in Table 2. An incremental increase of 2 m^3/ha was used for the processing sites, while the cutover volume remained constant throughout. As the study is to test whether or not in-forest processing sites introduce bias and decrease precision of the sample, incremental cutover volumes do not need to be trialled; this is based on the assumption that LIS produces unbiased predictions of cutover volume with random distribution of logs.

Table 2: Volume of modelled cutovers and processing sites

Cutover volume (m3/ha)	1	1	1	1	1
Processing area volume (m3/ha)	1	3	5	7	9
True volume (m3/ha)	2	4	6	8	10

6.3.4 Increased Sample Length

After running the base case, the model was run again to investigate how the estimates of volume changed with a change in sample size. The additional sample lengths used were 1,000 m (20 line segments) and 2,000 m (40 line segments). The choice of these lengths was to represent a range that made practical sense. As Interpine forestry do not typically sample with greater than 1,700 m for any single cutover, it does not make sense to sample much more than this. On the other hand, a sample of less than 1,000m would likely result in a lack of allowable precision to make use of the sample results.

6.3.5 Number of iterations for each set of model parameters

After much thought and trialling, a minimalistic approach was chosen for the number of iterations to use for each set of specific model parameters. The reason behind this was because of a time constraint, and the limitation of ModelBuilder to iterate LIS assessments. Therefore, 30 iterations were completed for each set of specific model parameters.

6.4 Analysis of Data

Analysis of the LIS assessment data was completed using the computer software programs Microsoft Excel and R Stats.

6.4.1 Estimated volume vs true volume

Graphical analysis was used to determine the range of LIS estimated volumes for each true volume. A students t-test was also used to test whether or not there was a significant different between the mean of LIS estimated volume and the means of the true volume. The t-test was based on the following hypotheses:

Null

μ_0 : There is no significant difference between the means of LIS estimated volume and the means of the true volume

Alternate

μ_1 : There is a significant difference between the means of LIS estimated volume and the means of the true volume

6.4.2 Error between estimated volume and true volume

Absolute Error

The absolute error was calculated as: the LIS estimated volume minus the true volume. The relationship between absolute error and true volume was then analysed graphically to determine the main trends in the data.

Mean and Standard Deviation of the Percentage Absolute

Similar to Peter Hall (1996), the mean absolute error was calculated as a percentage value to determine whether or not sampling is accurate; a percentage mean absolute error with no bias would be indicated as 0%. However, the precision of estimates was indicated using the standard deviation of the percentage absolute error, as it was in Bell et al (1996). It is best to analyse the precision as a percentage as it helps to determine the level of variation proportionately to the true volume.

7.0 Results

7.1 Verification of the LIS model

The absolute errors for the LIS assessments on a cutover under no distribution or orientation bias are displayed in Figure 8. There is a heteroscedastic relationship; indicating that as true volume increases, the variation of absolute errors also increases. The trend line of the data suggests that there is a very small level of bias, indicating a slight underestimation of true volume. However, the results of t-tests of significance for LIS estimate volume and the true volume (Table 3) indicate no significant bias (at alpha 0.05) for all true volumes except 8m^3/ha (p-value =0.02309). Therefore, it is best to assume the LIS model does contain a very small level of bias that should be treated carefully.

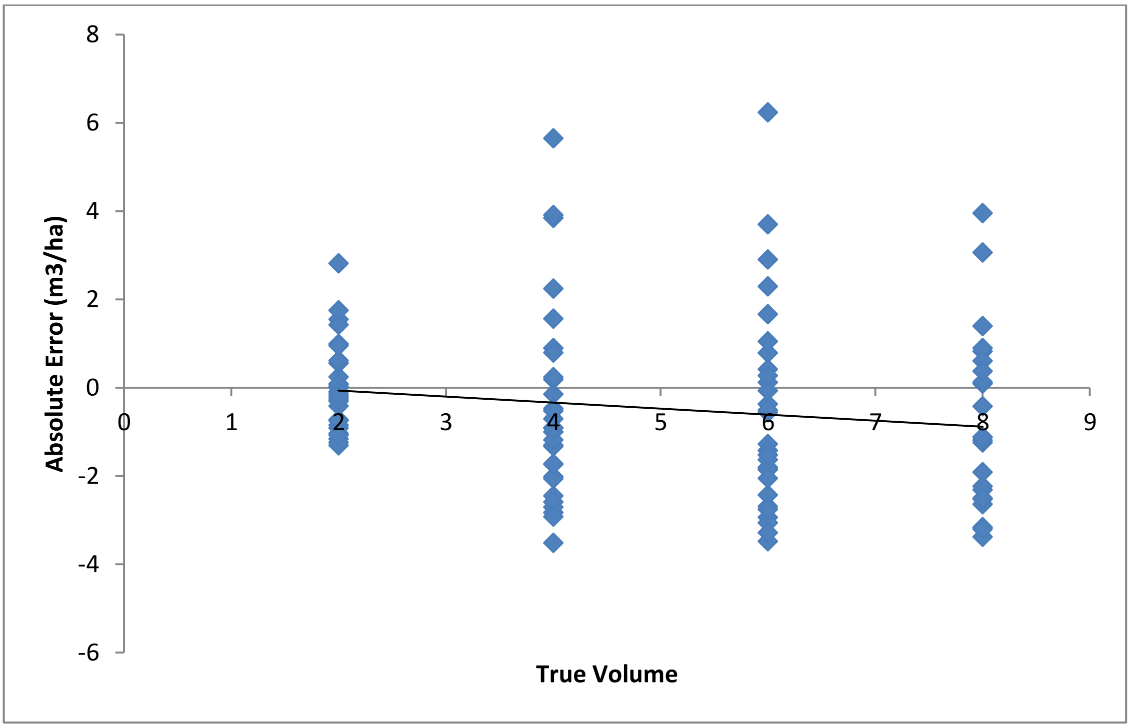

Figure 8: Absolute error for LIS assessment with no bias

Table 3: Results of a t-test for significance for unbiased LIS assessments

True volume (m3/ha)	Estimate volume (m3/ha)	Degrees of freedom (n)	t-value	p-value	Mean absolute error (m3/ha)
2	1.99338	29	-0.0358	0.9719	-0.00662
4	3.517424	29	-1.2191	0.2326	-0.482
6	5.382143	29	-1.4852	0.1483	-0.6178
8	7.127953	29	-2.399	0.02309	-0.872

7.2 Absolute Error

The absolute errors for LIS assessments of the modelled stand with a cutover containing 1 m^3/ha of log pieces are displayed in Figure 9. There is a heteroscedastic relationship between absolute errors and true volumes, as the range of absolute errors increases with increased true volume. There is a clear trend of bias, as the absolute error has a negative mean value, resulting in a general under prediction of the true volume remaining. This finding is supported as the difference in means between LIS estimate and all true volumes except 2 m^3/ha was significant at the 95% confidence level; alpha of 0.05 (Table 4).

There is a clear lack of precision of LIS estimates of volume, as is displayed in Figure 7. The variation of volume estimates is such that some estimates of volume are double that of the true volume, while other estimates are under predicting the true volume by almost 100%.

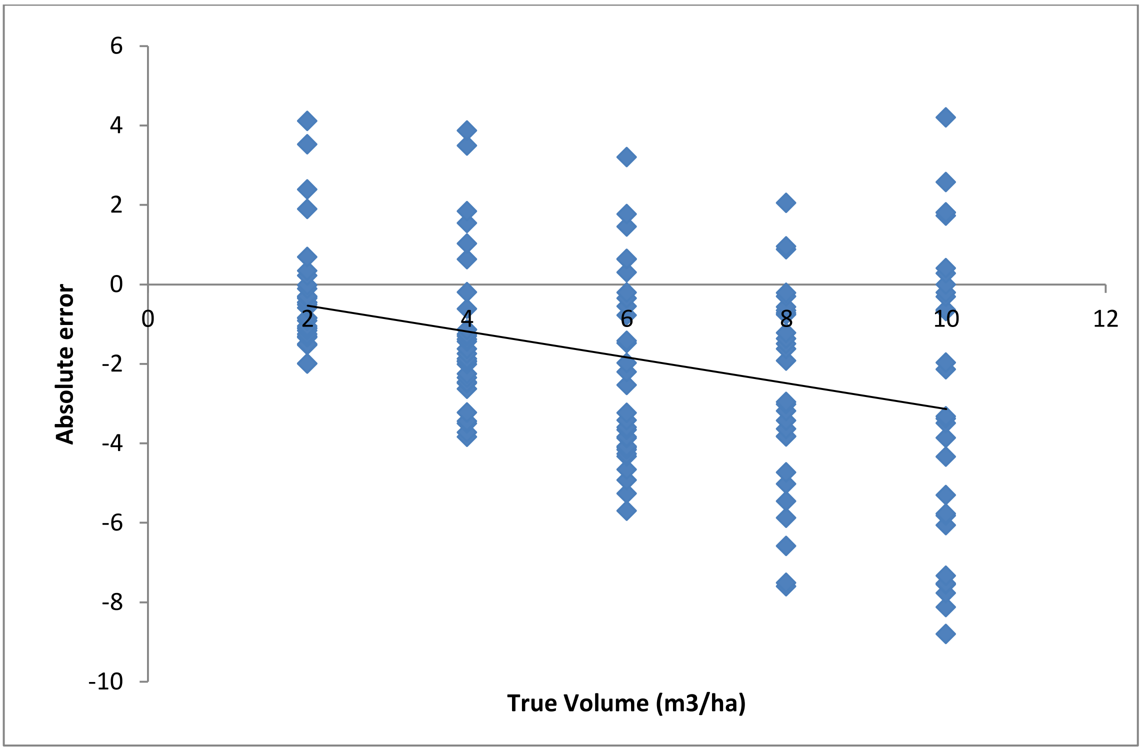

Figure 9: Absolute error and true volume with incremental processing area volume

Table 4: Results for a t test of significance for LIS assessments with distribution and orientation bias

Actual volume (m^3/ha)	Mean LIS volume (m^3/ha)	Degrees of freedom	t value	p value	Mean absolute error (m^3/ha)
2	1.7	29	-1.0	0.33390	0.0
4	2.8	29	-3.4	0.00174	-1.2
6	3.8	29	-5.2	0.00004	-2.2
8	5.3	29	-5.4	0.00001	-2.7
10	7.2	29	-4.1	0.00332	-2.8

The percentage mean absolute error for a cutover of set volume 1 m^3/ha is displayed in Table 5. The percentage mean absolute error is similar for all true volumes (at around -30%). The percentage mean absolute error is less for a true volume of 2 m^2/ha (-13.3%), likely because the cutover unaffected by distributional bias contains a proportionately higher volume under this scenario. However, it is clear there is a lack of precision of volume estimates for a true volume of 2 m^3/ha, as the standard deviation of the percentage absolute error is much larger than for the other true volumes (73.9%).

The standard deviation of the percentage absolute errors for a cutover of set volume 1m^3 is also displayed in Table 5. As the standard deviations of the percentage absolute errors are considerably larger than the percentage mean absolute errors, it can be determined that the LIS volume estimates were not precise. Precision of LIS assessments is a function of both the length of sample used, and density of material remaining on the cutover. This is shown as the standard deviation of the percentage absolute error decreases with increasing in true volume. The single exception to this is for a true volume of 10 m^3/ha, where there is a slight increase. This is unusual and should be considered as an error in the sampling strategy, possibly because of a lack of sample iterations.

Table 5: Mean and Standard deviation of the absolute error (%) for the base case sampling intensity

True volume	Mean absolute error (%)	Standard deviation of absolute Error (%)
2	-13.3	73.9
4	-31.0	49.2
6	-37.1	39.3
8	-32.9	32.1
10	-28.2	37.1
Total	-28.5	46.3

7.3 Change of Sampling Length

The mean and standard deviation of percentage absolute error is displayed in Table 6 for sampling lengths of 1,000 m and 2,000 m, respectively. It is clear that 1,000 m of sampling is not enough to produce consistent results, as the percentage mean and standard deviation of absolute error follow no noticeable trends. However, results similar to those produced for 1,500 m of sampling (Table 4) are shown for 2,000 m of sampling, as the standard deviation of the percentage absolute error typically decreases with an increase in volume, and therefore density. However, the increase in sampling length resulted in an increased level of bias, as the percentage mean absolute error is larger for 2,000 m of sampling that for 1,500 m of sampling (Tables 4 and 5).

Table 6: Mean and standard deviation of the absolute error (%) with a change from the base case sampling intensity

	1,000m Sampling (20 line segments)		2,000m Sampling (40 line segments)	
True volume	Mean absolute error (%)	Standard deviation of absolute Error (%)	Mean absolute error (%)	Standard deviation of absolute error (%)
2	-35.8	52.1	-29.4	57.1
4	-69.9	21.8	-42.3	40.5
6	-20.1	63.5	-42.9	32.5
8	-36.9	54.1	-40.7	33.7
10	-49.6	28.1	-35.0	26.7
Overall	-42.4	43.9	-38.0	38.1

8.0 Discussion

8.1 Accuracy of LIS assessments

8.1.1 Model Verification

It was determined that the LIS model probably contains a very slight level of bias in the sampling estimations of volume, despite the majority of t-tests confirming there was none. This is a significant finding that can be attributed to aspects of the simulation strategy used. Under the assumptions used, logs were created as line features with infinitesimally small width. This was an invalid assumption, as the probability of interception is slightly reduced due to the logs not actually being represented by an area, but instead, a vertical plane. Another invalid assumption was that all logs would lie within the cutover. However, due to a random location and random orientation, logs often crossed the cutover boundary, reducing the possibility of interception. Therefore, it is likely the reduced the number of overall interceptions lead to a slight underestimation of volume.

8.1.2 Bias of LIS assessments

Clumped distribution caused the LIS method to inaccurately estimate true volume remaining on site post-harvest, as LIS assessments generally under predicted the true volume. It was thought that orientation bias also contributed to the bias of volume estimates; however, Bell et al (1996) concluded that logs under orientation bias did not result in biased estimations of merchantable volume. Although the orientation bias for this study differed from Bell et al (1996), it was only confined to only a very small area of the cutover (4% of total area). Therefore, a determination can be made that clumped distribution of logs was the main cause of bias in the LIS estimates.

8.1.3 Solutions to remove bias from LIS assessments

The reason that clumped distribution causes bias in the LIS estimates is that the sampling does not intersect the logs that represent the majority of them volume in the cutover. The likely solution to this problem would be to increase sampling, and therefore, increase the likeliness that logs will be intersected. However, this does not work for the LIS method as the volume estimate is a function of the total length of sampling used, as well as the density of the stand. This was demonstrated by an increase in sampling from 1,500 m to 2,000 m causing the overall percentage mean absolute error to increase (-28.5% to -38.0%), resulting in an increase in bias of LIS estimates, despite standard deviation of percentage absolute error decreasing (46.3% to 38%).

The most practical solution to remove bias from LIS when clumped distribution exists is to treat the cutover and the in-forest processing sites as separate populations measured using different sampling techniques. LIS would be used to quantify the volume that is left on the cutover that is random distributed. The LIS operating procedure would be modified to view in-forest processing sites the same as landings. As such, any single segment that intersects an in-forest processing site would make a right hand turn at the point of intersection to track away from the in-forest processing area. Discretion would be taken by the individuals completing the LIS survey to distinguish the boundary of each population.

Two possible sampling methods could be used to estimate volume of the in-forest processing sites. The first involves complete enumeration of the in-forest processing sites by means of: length, LED, SED, and total area measurements. Volume would be determined under this method using Smalians formula, with the assumption of normal taper. However, this method is limited because of the orientation bias and number of logs that occur on such sites, with small piles of awkwardly stacked logs that increase difficulty of measurements. The difficulty of taking log measurements increases the time to produce a volume estimate for that particular area, and therefore, the total cost of quantifying the remaining merchantable volume on the cutover will increase dramatically; this is an undesirable result. It is recommended that Interpine Forestry review the practicality of this method.

The second possible method involves using a modified method of LIS, whereby transects are run directly perpendicular to a suspected mean angle of log orientation. Under this method, the probability factor $\pi/2$, which allows the elliptical cross sections of intersection to be summed as circles, does not apply. This is because the line intersects within a relatively perpendicular range, meaning that elliptical cross sections are not predominant as they are with random orientation. Therefore, a new factor would have to be derived to represent the possible range for which the sampling line might intersect the logs. This range is not entirely obvious and is determined by the exact orientation of the logs that are being intersected, which is likely to change between different sites. The method is further complicated by the awkward stacking of logs previously mentioned; this increases the practical difficulty of taking diameter measurements.

8.2 Precision of LIS assessments

The LIS method does not produce precise estimates of the true volume remaining on site when logs are not randomly distributed and are under orientation bias. This was shown by the substantial size of the standard deviations of percentage absolute errors. This is not a new finding; with similar findings in Van Wagner (1968) and Bell et al (1996) leading to the conclusion that results from individual assessments may be so inaccurate they are practically worthless.

8.3 Implications for Rayonier/Matariki forests

The fact that clumped distribution of logs causes the LIS method to underestimate the total volume of merchantable volume on the cutover is worrying for Rayonier. If the majority of assessments produce an estimate volume that is less than the true volume, Rayonier stand to significantly lose out, as they undercharge the stumpage contractor for the remaining merchantable volume. With mean absolute errors typically in the range of -30% , it is likely that over a long period of time this will result in Rayonier undercharging the stumpage customers for remaining merchantable volume by around 30%.

The problem raised by Rayonier staff and stumpage customers, that particular LIS assessments were overestimating the true volume in the cutover, is addressed by the lack of precision of sampling estimates. The lack of precision means that volume is frequently inaccurate; as it is overestimated and underestimated. It is interesting that the few overestimations in LIS volume led to an issue being realised that can be described by a lack of sampling precision, despite the greater issue being that LIS more often than not underestimates the true volume.

Given that a lack of precision has been identified, it would make sense that the solution is to increase the sampling length used. However, it is not practical to use more than the

1,500 m to 1,700 m (30-34 line segments) that Interpine use operationally (Herries, 2013). The reason for this length of sampling is a combination of the expected precision of the LIS volume estimate and keeping assessment costs minimal. An LIS assessment of 30-34 line segments will costs Rayonier roughly between $800 and $900 a day; this is based on each segment costing between $26 to 27 and 30-34 segments being installed per day (Herries, 2013). Therefore, increasing sampling beyond the operational LIS procedure of Interpine Forestry will result in unnecessary costs for Rayonier and lead to a reduction in the realised monetary gain achieved by quantifying the remaining merchantable volume.

8.4 Limitations

ArcGIS and Modelbuilder were chosen to build the LIS assessment model because of the user friendly interface and the availability of personnel to assist with ArcGIS issues. However, a large number different ArcGIS geoprocessing tools were required to run individual assessments in Modelbuilder, meaning that Modelbuilder was often overloaded; this resulted in frequent crashes of the software. Therefore, the capability of the program to run a large number of LIS assessments was restricted, as multiple iterations without manual interference was not possible.

The software that was intended to make the running of multiple iterations of LIS assessments an easy task, actually turned out to be incredibly inefficient. A possible solution to this problem would have been to script the model using Python scripting. However, this requires a very high level of expertise and will not necessarily stop the crashing of the ArcGIS software, as the software is generally unreliable.

The number of sample iterations was originally intended to be far greater than was actually used and was in the range of 500-1,000. This number was based on the findings of Pickford and Hazard (1978), who found that within less than 700 iterations, the expected values of residue volume and sample variance stabilised. However, the problems with ModelBuilder limited the ability to achieve such a number of iterations in a reasonable time period. Therefore, it was decided operationally that the total number of iterations could be a maximum of 30. This was based on a time constraint that each assessment took between 5-10 minutes to complete, without also considering lost time due to crashing of ArcGIS every few runs.

It became evident through data analyses that although the data showed significant trends, the values for precision and accuracy were not as statistically strong as they would be with an increased number of sample iterations. This was particularly evident for the LIS assessments that used only 1,000 m of sample line, where a significant trend was shown that indicated bias of predictions (Table 5). However, the level of bias for each level of volume on the cutover was not completely quantified, with non-consistent estimates of precision and bias. By increasing the number of sample iterations, the true value of bias and precision of estimates would have been determined.

8.5 Further Study

Further study regarding the effects of distribution bias on the LIS method would be useful. A comprehensive study using a larger number of sampling iterations would be beneficial to investigate the possibility of treating in-forest processing sites as a separate population, given the orientation bias that occurs through these sites.

9.0 Conclusions

The primary objective of this study was to determine whether or not the LIS method for assessing logging waste is appropriate, given a clumped distribution of logs produced by processing at central sites in cutover before using a forwarder to extract to the landing. It was determined that the conventional LIS method is not appropriate given these harvesting methods, as a level of bias was found in sampling that showed the LIS method underestimated true volume. The significance of this bias was determined using t-tests (alpha = 0.05).

It was determined that LIS volume estimates were not precise, with a range of volume estimates from more than double the true volume, to estimates of no volume. An increase in sampling length by a third was found to increase precision by only a small amount. Therefore, increasing sampling was not determined to be worthwhile in a practical sense, as the increase in precision did not match the extra cost that would be incurred to achieve it.

It is recommended that Interpine carry out further work with regards to the results of this study. A possible approach is to determine a standard operating procedure that would allow areas of clumped log distribution and areas of random distribution to be treated as separate populations. In this way the accurate LIS method can be applied to random log distribution, with an alternative sampling method applied to areas of clumped log distribution.

10.0 References

Bailey, G. (1970). A simplified method of sampling loggine residue. *The Forestry Chronicle 46*, 228-294.

Bate, L., Torgersen, T., Wisdom, M., & Garton, E. (2009). Biased estimation of forest log characteristic using intersect diameters. *Forest Ecology and Managment*, 635-640.

Bell, G., Kerr, A., McNickle, D., & Woollons, R. (1996). Accuracy of the line intesect method of post-logging sampling under orientation bias. *Forest Ecology and Management*, 23-28.

Brown, J. (1974). *Handbook for inventorying downed woody material. .* United States Department of Agricuture Forest Service.

Brown, J., & Roussopoulos, P. (1974). Eliminating biases in the planar intersect method for estimating volumes of small fuels. *Forest Science 20*, 350-356.

De Vries, P. (1973). *A general theory on line intersect sampling with application to logging residue inventory.* Wageningen, The Netherlands: Medelingen Landbouw Hogeschool.

Hall, P. (1996). *CUTOVER WASTE ASSESSMENT - A Comparison of Sampling Techniques and Intensities.* Rotorua: LIRO.

Herries, D. (2013). *Cutover Residue Assessment Using Line Intercept Sampling : Practioners Guide to the Methodology.* Rotorua: Interpine Forestry Ltd.

Howard, J., & Ward, F. (1972). *Measurement of logging residue - alternative applications of the line transect method.* Portland, Oregon: U.S Department of Agriculture.

Linnel Nemec, A., & Davis, G. (2002). *Efficient of six line intersect sampling designs for estimation volume and density of coarse woody debris.* Nanaimo: Forest Service British Columbia.

O'Hehir, J., & Leech, J. (1997). Logging residue assessment by line intersect sampling. *Australian Forestry, 60:3*, 196-201.

Patterson, D., & Doruska, P. (2002). A new and improved modification to Smalian's equation for butt logs. *Forest Products Journal Vol 54, No. 4*, 69-73.

Pickford, S., & Hazard, J. (1978). Simulation Studies on Line Intersect Sampling of Forest Residue. *Forest Science 24*, 469-483.

Pickford, S., & Hazard, J. (1986). Simulation Studies on Line Intersect Sampling of Forest Residue, Part II. *Forest Science 32*, 447-470.

Sutherland, B. (1986). *Standard Assessment Procedures for Evaluating Silvicultural Equipment : A Handbook.* Ontario: Canadian Forestry Service.

Wagner, V. (1968). The line intersect method in forest fuel sampling. *Forest Science 14*, 20-26.

Wagner, V. (1982). *Practical aspects of line intersect sampling.* Ontario, Canada: Petawawa National Forestry Institute.

Warren, W., & Olsen, P. (1964). A Line Intersect Technique for Assessing Logging Waste. *Forest Science 10*, 267-276.

Woldendorp, G., Keenan, R., Barry, S., & Spencer, R. (2004). Analysis of sampling methods for coarse woody debris. *Forest Ecology and Management 198*, 133-148.

11.0 Appendices

Appendix 1: Estimated volume vs true volume

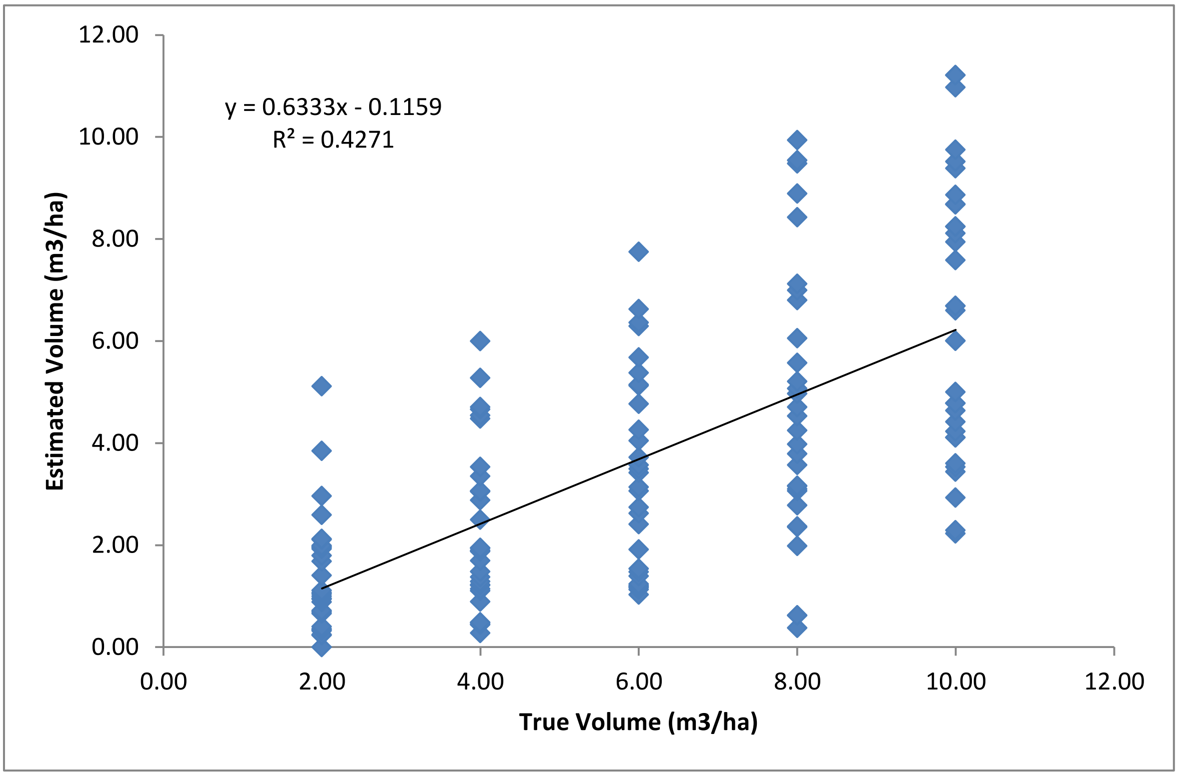

Figure 10: Estimated volume vs true volume – 1,500 m sampling

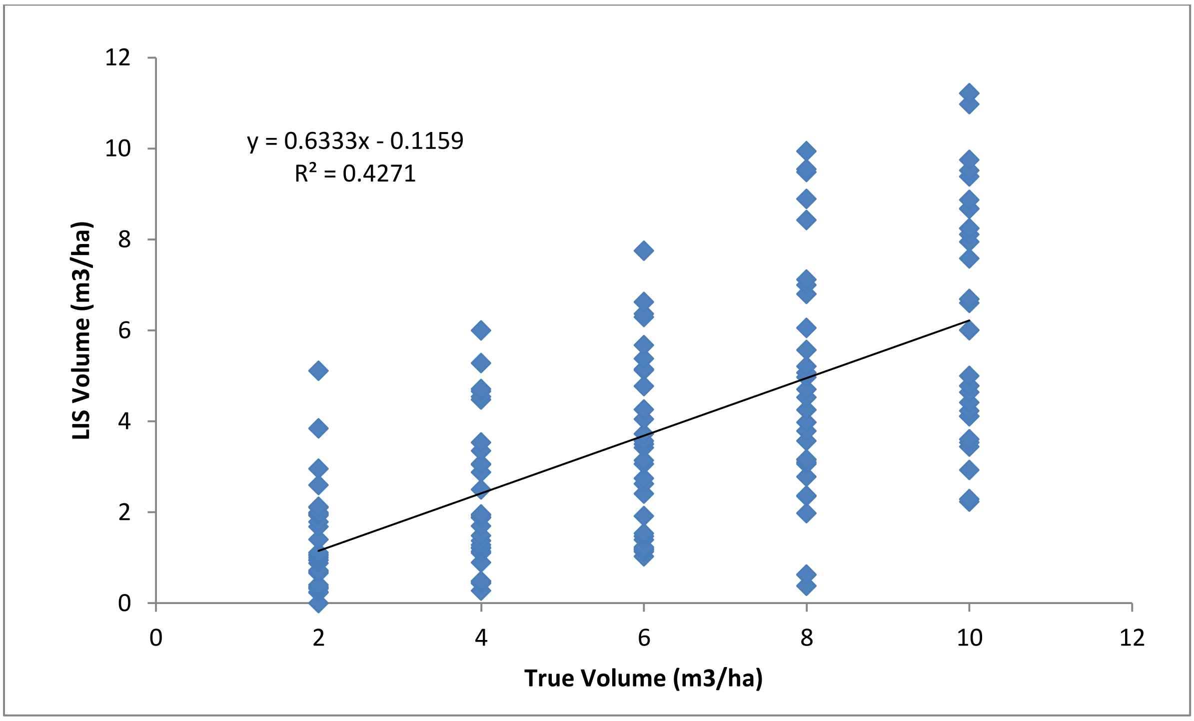

Figure 11: Estimated volume vs true volume – 2,000 m sampling

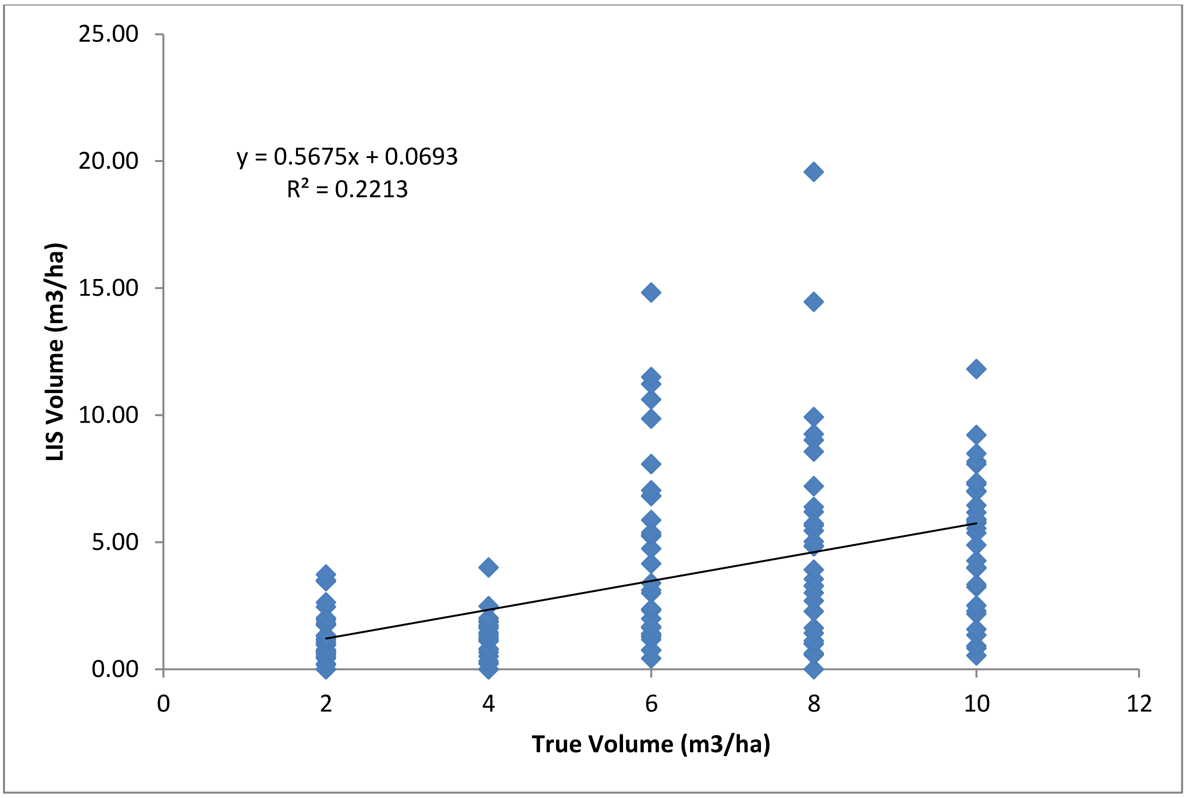

Figure 12: Estimated volume vs true volume - 1,000 m sampling

Appendix 2: Absolute errors vs true volume

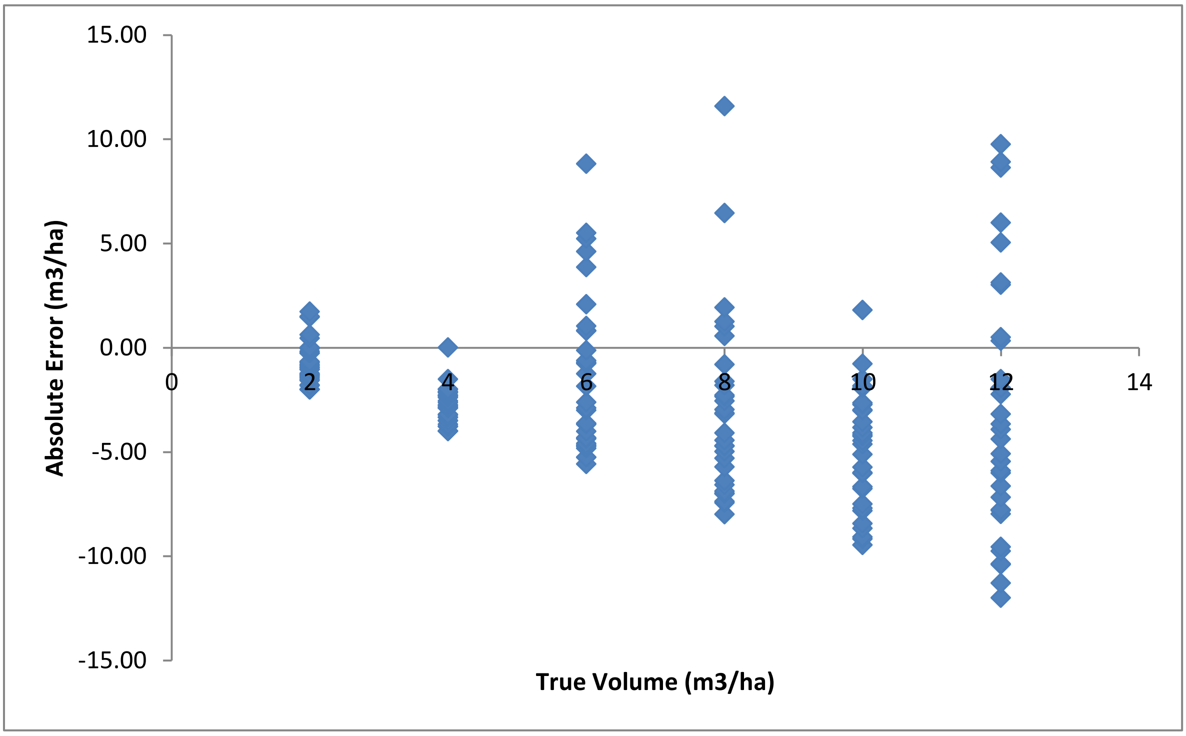

Figure 13: Absolute error vs true volume - 1,000m sampling

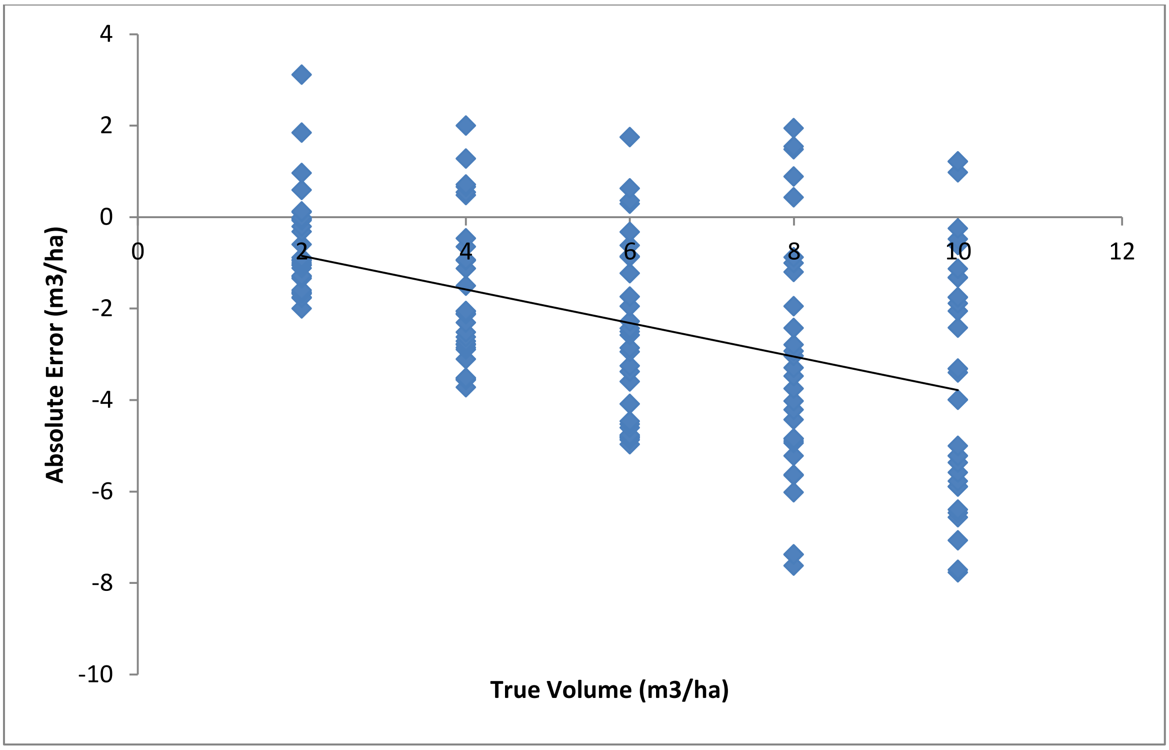

Figure 14: Absolute error vs true volume - 2,000 m sampling

Appendix 3: Field testing distributions

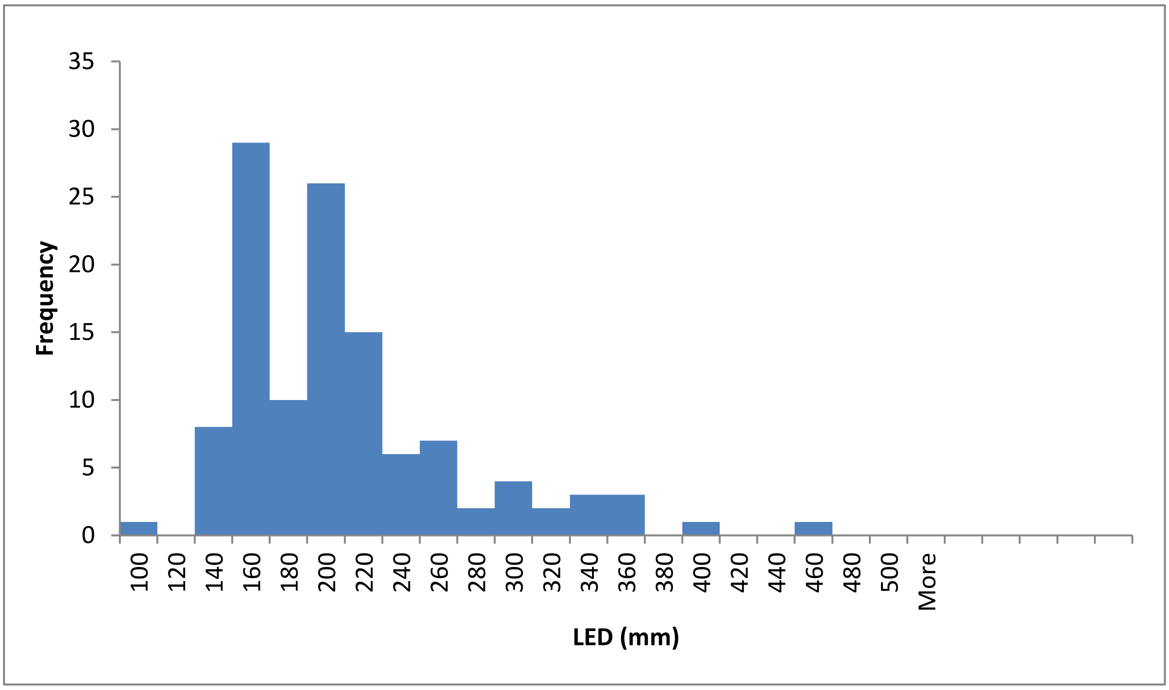

Figure 15: Distribution of LED from field testing

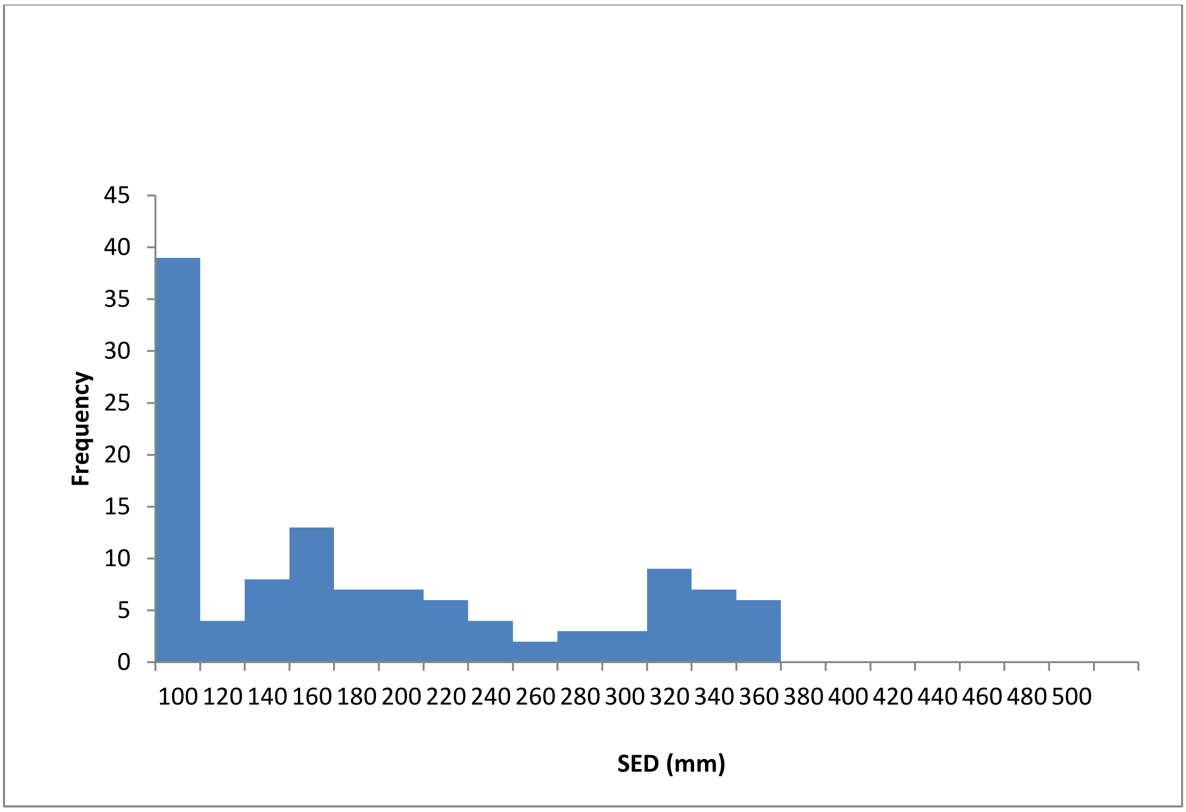

Figure 16: SED distribution from field testing

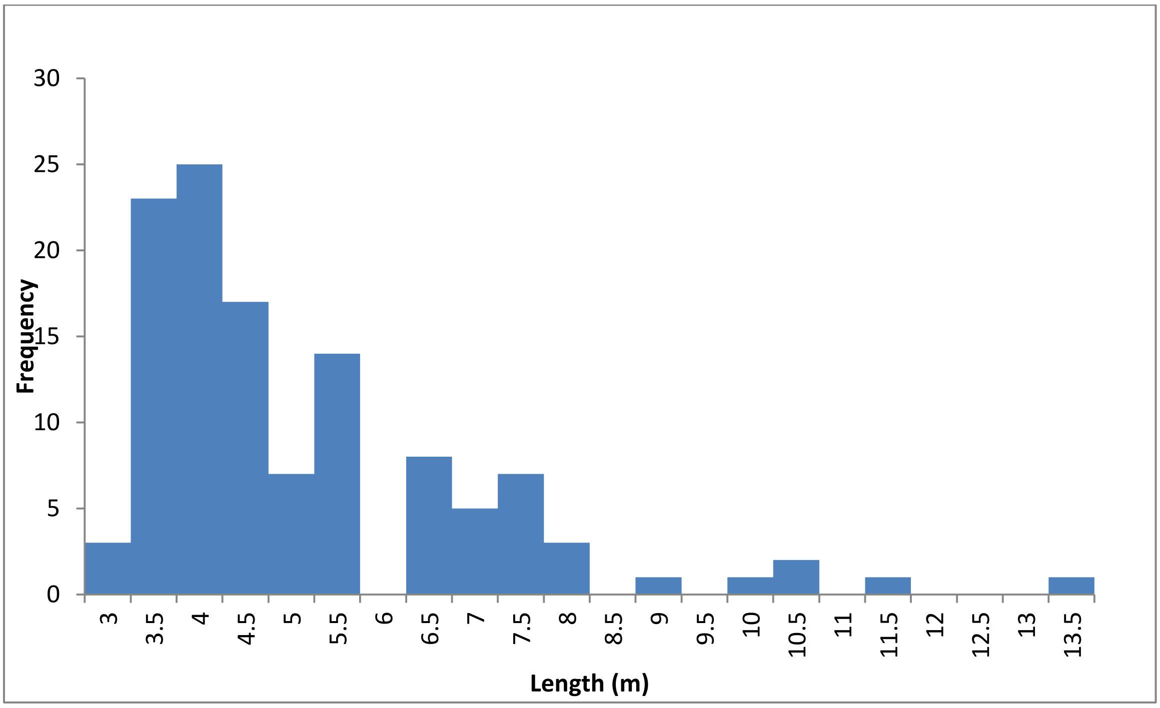

Figure 17: Length distribution from field testing

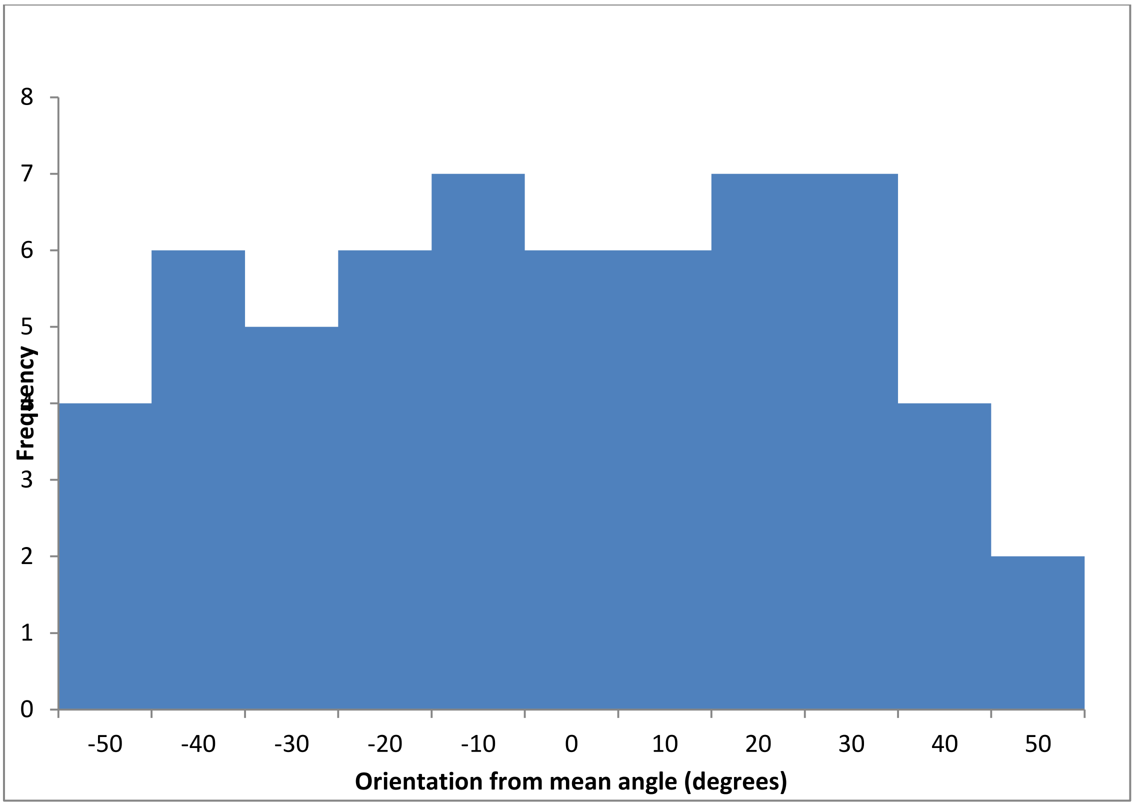

Figure 18: Distribution of orientation angles about the mean