The Implications of Log Taper on the Expected Difference of JAS Scaling to 3D Scale in New Zealand

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Bachelor of Forestry Science with Honours by:

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Abstract

As a result of the strong price and demand trends observed in the export market, the importance of value recovery from log exports is emphasised by suppliers/owners.

Two methods of analysis were used for the duration of this study. The first was using real log measurements, utilising SED, LED and Length of logs. The second was through modelling of volume, estimated using the same three variables as the above. This data was presented in a matrix that predicts taper and estimation differences based on the log measurement inputs.

Analysis was performed utilising two datasets; one from the North Island (East Coast) and one from the South Island (Southern South Island). The taper ranges for each study area were calculated as base data. The North Island on average had taper of 1.45cm/m, whereas the South Island data showed average taper of 1.83cm/m. The logs were separated into their respective grades; overall the logs that displayed the most taper were South Island Pulp and K grade logs.

The overarching question of the study was to determine the volume logs measured with a JAS scale and then compare that to the volume predicted by a 3D scale (assumed to be as close to the true volume as possible for this study). The analysis showed that for the South Island estimation differences of; -15.8%, -4.7%, 3.7% and 6% for Pulp, K, A and Pruned grades respectively. The North Island dataset showed estimation differences of; 2.7%, 8.7%, 6.4%, 3.5% for Pulp, KI, A and Pruned grades respectively. The main trend that is observed through these estimations of difference is that the smaller SED logs; South Island Pulp grade (average SED of 21.4cm) and South Island K grade (average SED of 27.5cm) are more likely to be underestimated. The remaining log grades for the North and South Island all have average SED values over 30cm, therefore it can be assumed that when the SED is over 30cm, the difference of JAS/m^3 will be overestimated. Using the prediction matrix created, the taper that is required for underestimation to occur for small SED logs (10-20cm) which are seen as the most susceptible to differences are; 0.276 – 0.925cm/m for 5.8m logs and 0.421 – 1.447cm/m for 3.8m logs. The tapers required for larger SED logs are larger and tend not to be underestimated using JAS.

The study highlights the tapers and associated differences of JAS/m^3. Knowledge of the causal factors of this difference is valuable for exporters in order to adjust prices etc.

Keywords: *export, logs, Japanese Agricultural Standard (JAS), taper, difference, estimation, conversion, JAS/*m^3*, forestry*

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Abbreviations:

3D = Three-dimensional

F.O.B = Free On Board

GDP = Gross Domestic Product

JAS = Japanese Agricultural Standard

LED = Large End Diameter

SED = Small End Diameter

1. Introduction

The log export industry is an important market for forestry operations in New Zealand, exporting 57% of all roundwood production in 2016 (MPI, 2017). It is often the most profitable route for owners and managers who are selling harvested radiata pine logs. The estimation of the volume of each log is important as the customer pays on a per cubic metre basis. If the scaling method used is underestimating the volume of logs, the owner is potentially selling more volume than they are paid for.

JAS scaling has been the industry standard method for the measurement of export logs for several years. Some issues with JAS scaling have been highlighted through previous literature and this study aims to build on those findings.

The purpose of this research is to quantify the impact that taper has on volume differences when logs are measured with two different methods; JAS scaling and 3D scaling (assumed to be the closest to a true volume).

2. Problem Statement

New Zealand exporters calculate the volume of export logs using the Japanese Agricultural Standard (JAS) scale. The JAS scale uses only the small end diameter and length to estimate volume and through the review of previous literature it has been found that taper has the most impact on estimation differences between JAS and true formula.

The problem that has been derived through review of the literature reflects the idea that there are no accurate/updated taper ranges for export logs throughout the study area. The problem statement that has been formed from this observation is as follows;

"What are the taper ranges that are observed throughout the study area and how does this taper impact the potential for accuracy differences in JAS scaling when compared to a 'true volume (utilising 3D scale to be assumed as true)?"

Furthermore, the study will aim to provide exporters, owners and forest managers with knowledge on how the volume of their logs may present as different to a true volume when exported using JAS scaling.

The implications of the omission of accurate taper functions are differences between JAS and true cubic metre measurements. This has potential to lead to monetary loss for the exporter/forest owner, but also means the log trader abroad can upscale the logs to turn a profit.

2.1. Research Questions

Two main research questions are identified as being crucial in order to answer the overall problem. Although these two questions have been identified, there are still several other areas of focus that will be noted throughout the study. The two research questions are:

1. What are the log tapers that are observed in export logs throughout New Zealand?
2. What is the expected differences between volumes estimated using the JAS formula and the true (3D scale) volume per cubic metre?

3. Literature Review

In order to gain an in depth knowledge of the topic and the surrounding influences of scaling, previous literature and information is reviewed. The topics of review are varied to ensure that a broad spectrum of information is covered.

The overarching question that is to be answered by this dissertation is how taper impacts the difference between JAS volume and true volume of logs. Any gaps that are found within the literature will be highlighted. The topics that will be covered in this review range from industry backgrounds to set the scene for the nature of the study, to the current work done on scaling in New Zealand. In particular there are five main areas to review; the industry background, scaling/log measurement history, JAS scaling, alternatives to JAS and identification of gaps in the research.

3.1. Industry background

Log scaling and measurement is only one area of interest within the forestry sector. It falls under one of the key market destinations for timber, this being the export market for logs. Nicholls (2017) provides a review that highlights the importance of the export market for New Zealand's forestry industry. Some key areas of interest and concern for New Zealand include the fact that we export >50% of harvested volume and of this 70% is sent to China (Nicholls, 2017). The reliance on China as a customer in recent years has led to some concern of the stability of the export market, however due to the large scale, these concerns are not profound.

Log exports are a very important market for the forestry industry, contributing a large portion of the total of $NZ5.4 billion total forestry exports (MPI, 2017). Understanding the true volume of export logs is very important because errors in volume estimation will lead to incorrect price signals and incorrect inferences about the market value of different log products.

3.2. Scaling (Log Measurement Background)

Since logs are a commodity product, the only real differentiator is the size/volume of each log. As a result of this they have always been sold based on the measurement of each log. The measurement of these logs has changed through time due to technology developments and demand of accuracy from the customers. Logs are sold as a volume that is measured under-bark, therefore excluding the unused residues.

There have been several changes to the way that logs have been scaled to assume the export value and volume of each log. Originally logs were scaled using 2-dimensional log volume tables that utilised a single measurement of the small end diameter (SED) and the length of each log (Ellis J. C., 1993). During the late 1960's the tedious nature of using look up tables to estimate the volume of each individual log became an issue, so exporters looked to find an alternative. The alternative was to measure the logs using weigh scaling to provide accurate weights for sale (Ellis J. C., 1993). Weight to volume conversion factors are needed to estimate the volume of the logs from the weight of the logs and bark (Ellis & Crawley, 2014).

During this time (1970s) a new scaling technique was introduced utilising a minimum of three of a possible four variables. This formula was a single three-dimensional equation that would replace the look up tables previously used to scale logs (Ellis J. C., 1993). The measurements used were; small end diameter (SED), length, large end diameter (LED) or average taper.

This method was used for several years until the Japanese Agricultural Standard (JAS) was introduced in the late 1960's, however it was permanently used from the 1980s (Anon, 1967). JAS in theory was an adaptation that excluded the use of LED in favour of taper estimates and averages (Ellis J. C., 2011). Due to the difficulty of measuring stacked logs and trying to ensure the correct SED and LED for each respective log is measured, the formula was much more effective than the previous 3D scale in terms of labour needed (Ellis J. C., 1993).

It is important to note that the current scaling system still utilises the weight of the load as a check against the JAS volume that is estimated using hand scaling. This means that each load scaled has a tonne to JAS volume conversion rate.

3.3. JAS Scaling

The Japanese Agricultural Standard (JAS) was initially introduced in 1967, but did not become the industry standard for scaling logs until the ~1980s (Anon, 1967). Currently the vast majority of export logs are exported using JAS scaling, with the exception of high value unique timbers (native timber).

The inaccuracy of JAS was soon highlighted however and several studies have shown that there are disparities between the JAS volume and the 'true' cubic metre volume (Ellis, Sanders, & Pont, 1996; Ellis J. C., 2011; Ellis J. C., 2016). These differences have caused scepticisim among forestry professionals as to the accuracy of JAS and cause worry that value may be lost as a result of this.

JAS is measured using two separate formulae for different log lengths (Ellis J. C., 1994):

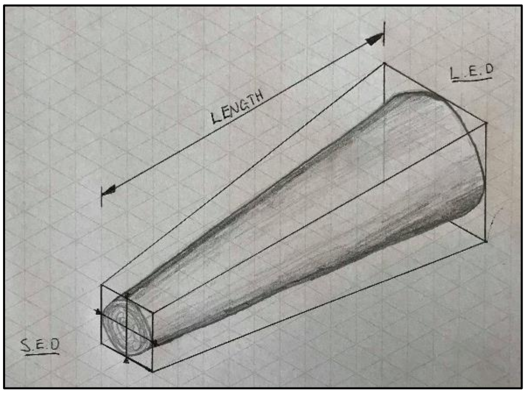

__Figure 1:__ JAS formula representation for logs equal to or greater than 6m in length

For logs larger than 6m (figure 1)

$V(m^3) = (D+[L'-4]/2)^2 * (L/10,000)$

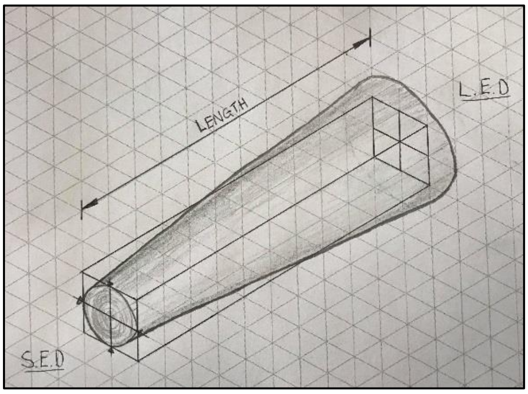

__Figure 2:__ JAS formula representation for logs less than 6m in length

For logs less than 6m (figure 2)

$V(m^3) = (D^2*L)/10,000$

D= Small end diameter

L = Length

L' = Length rounded down to the nearest whole number

(L'-4)/2 = taper factor

For the purpose of this study only logs measured using the less than 6m JAS formula will be utilised (figure 2). The difference between the two formulae is the addition of a taper factor for logs equal to or greater than 6m in length. Taper is effectively ignored for logs that are less than 6m in length (Fonseca, 2005). This results in short logs being underestimated on average and long logs being overestimated (Ellis J. C., 1993). JAS determines the area of the log assuming a square that has the same cross dimensions as the measurement of the SED. Fonseca, (2005) estimates that this method can overstate the volume of the log by up to 27.3% due to the area difference between a square cross section and not a circle. A second report by Ellis (2011) states that this estimation difference can be ~40% when certain log criteria are met.

Difference in JAS is caused by a variety of factors with SED, log length and taper being the leading causes. Ellis (1996) found that taper was the worst causal effect for difference in measurement. This research was continued by Ellis (2010) who concluded that export logs that are measured using the JAS formula are underestimated, when logs have high taper.

Taper causes differences as a result of the JAS formulae that are used, mainly due to the omision of the taper function for logs that are less than 6m in length. This becomes a problem as the most common log grades and lengths currently exported are A and K grade logs at lengths of 3.8m and 5.8m (Duval, 2016). There is some 'fixing' of the equation as a result of the missing taper function through the form of rounding down the SED measurements to the nearest even centimetre (Fonseca, 2005; Ellis & Crawley, 2014).

3.4. Issues regarding log taper

Due to the issues that taper can cause when exporting logs it is important to know how and why taper changes and what drives the taper that is measured in export logs. Some broad areas of plantations contribute to the taper of the tree as a whole and then consequently the logs we export. These areas include but are not limited to; the environment (climate, season, region, elevation etc.) and silvicultural practices applied. Steps can be taken through management to mitigate the taper causing variables.

The environment is more variable and less controllable in terms of managing plantations to avoid taper issues. Ellis (2010) conducted a study throughout New Zealand, comparing JAS measured logs with logs that were re-measured using the 2D scale proposed by Ellis (2011). The 2D scale is seen as a more accurate measurement of the logs as it includes a taper allowance in the formula (Ellis & Crawley, 2014). The study concluded that the areas with the largest difference in terms of JAS vs 2D were Canterbury/Otago and the area that showed the smallest difference was Gisborne. Another aspect of the environment is the season of harvest. This can alter the weight of the logs and skew the conversion of JAS/tonne. Low conversion values are common in the winter months when the logs are heavier and higher conversions are documented in summer months (Ellis J. C., 2016). This can become an issue more so for the perception of volume to weight conversions. People expect that heavy logs will in turn mean a larger volume, however this is not the case. Furthermore, Ellis (2011) showed results to suggest that the higher altitude sites in the South Island yielded logs with high tapers. A combination of these environmental factors can lead to high taper logs that cause differences in JAS volume estimation.

Silvicultural practices can have a profound impact on the taper that is observed for export logs. Several studies have detailed how correct management can reduce the taper of trees. Mason (2004) reviewed the impact of stocking density on wood properties and found that when stocking is increased the taper of trees decreases. This is due to competition for light forcing trees to focus growth in height, rather than diameter initially. This idea also ties into a study by Punches (2004) that discussed the impact of crown size on taper of trees. Punches (2004) found that when the crown of the tree was reduced the taper also reduced due to larger growth rings occurring in the cambium area when the crown is present, so when it is removed more uniform growth occurs along the stem. Punches (2004) therefore suggests that the removal of the crown through pruning therefore means that taper is decreased. Further study has suggested that logs taken from the bottom of the tree will have less taper on average than those taken from near the top of the tree (Blazier, et al., 2013). Although taper can be influenced heavily by butt flare and other growth phenomenon that occur in the butt log, Fonseca (2005) highlights this point when discussing the stem form of trees and the different sections of a tree (figure 3). A contrasting view on how pruning effects the taper of a tree is presented in a more recent study from Fernández, et al., (2017). The study found that stands that had high management (pruning and thinning) had pruned butt logs that had higher taper than unpruned butt logs. The contrasting views cause some controversy as to the effects of pruning on taper. There is potential that this observation is caused by stocking, as with pruned stands stocking is often lower to allow for larger diameter growth. Based on Fonseca (2005) log grades such as Pruned and A should in theory have less taper and JAS differences than KIS or K grade logs which are usually taken from closer to the top of a tree. However this could change with pruned logs being higher in taper (Fernández, et al., 2017). A comparison between pruned grade logs and A grade logs will provide some insight into this discrepancy.

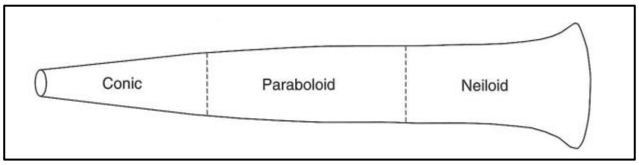

Figure 3: *Stem form caused by differing tapers (Fonseca, 2005)*

3.5. Alternative log measurement methods to JAS

There are several variations used for scaling logs, some are utilised in the domestic market only as they are more suited to smaller consignments or are for more valuable timbers. Several alternatives to JAS are available, although due to the current market climate they are not as accepted/familiar. The formulae for each respective measurement method can be found in appendix A.

3.5.1. Three-Dimensional Scale

The three-dimensional scale (3D) is a common domestic scaling technique used for logs, posts and poles (Ellis & Crawley, 2014), it is the most widely used scaling methods for logs that are used in sawmills etc. The scale is also used for high value timber and as a means to check the accuracy of export log scaling. 3D scaling differs from JAS as it measures both the small end and large end diameters. 3D scale also uses an averaging method for the diameter measures instead of rounding down, such as in JAS scaling.

3.5.2. Two-Dimensional Scale for Export

The two-dimensional (2D) scale for export is an alteration of the 2D scale that is used for domestic logs. Proposed by Ellis (2011) the 2D scale looked to improve the JAS scale in terms of accuracy. This was done through the addition of a taper allowance included in the formula. The measurement method also allows the use of the average of two SED measurements to be used as opposed to JAS which uses the smaller of two rounded down values (Ellis & Crawley, 2014).

3.5.3. Newton Scale

Newton measurement is another alternative that is employed mainly for the domestic log market. This technique is closely related to Smalian scale, although it is used for logs that don't have the need for such detailed sectional measurement. Newton scale uses the large, small and mid-girth diameters to form more detailed measurements of stem form. The method is suitable for large logs that have consistent but large taper (Ellis & Crawley, 2014).

3.5.4. Huber (mid-girth) scale

Huber scale differs from most other methods as it does not measure large end or small end, relying only on the mid-girth measurement and the length of the log. This method assumes that the log is cylindrical in shape and that the volume is estimated using log length multiplied by the area of a circle, based on the mid-length diameter (Ellis & Crawley, 2014). This method has been known to understate volume as not all logs are close enough to cylindrical in form (Ellis J. C., 2005).

3.5.5. Smalian (sectional measurement) scale

Smalian scale is a specialised formula that incorporates several measurements at even increments along each log. This method is most useful when 'close' to the exact volume of the log is required. The taper of the log is not such a large difference causing factor in this method, due to the sectional measurements taken reducing the effects of taper over the length of the log (Ellis J. C., 2005; Ellis & Crawley, 2014). However, Smalian scaling is highly specialised and is not suitable for large scale operations, although it is used to check/assess the accuracy of other measurement formulae.

3.6. Gaps in research

Through review of the literature regarding JAS scaling and the associated differences it is determined that the major causal factor is log taper. Although it is well documented that taper has a large impact on estimation differences, there is no quantified indication as to what these volume differences are when taper changes. For example, it is not known how a log with 2cm/m taper will perform when the volume is estimated using both JAS and 3D scaling.

This study will utilise real life log data to look at the idea that taper causes the largest differences in JAS to m^3 differences and quantify the differences for different log grades and lengths throughout New Zealand.

4. Methods

This study aims to detail the difference that is associated with taper, in terms of JAS to m^3 differences. There are several facets to this study in order to collect data, analyse this data correctly and then be able to present the data in a way that answers the overarching question. The measurement methods and data collection techniques applied follow industry standards as highlighted through the review of literature (section 2). This section will detail all methodology from data collection through to data analysis.

4.1. Log measurements

Log measurements are the basis of this study, as the variables of interest consist of the three most important measures of a log. The method of measurement applied throughout this study is 3D scaling as this provides the required values of a log and also allows for JAS estimation through the same measures. A 3D measurement consists of measuring the small-end diameter (SED), the large-end diameter (LED) and the length of each log individually.

Measuring each log in this fashion is not feasible for large scale operations due to the difficulty in identifying the corresponding SED and LED when the logs are on a truck, in log piles or in bunks. Therefore, JAS scaling is used for larger operations and this 3D method is used to 'check' the accuracy of JAS over time.

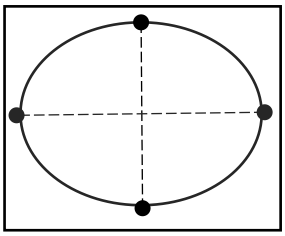

Figure 4: *Measurement of SED/LED at right angles to smallest diameter*

Log measurements used for this study use the three-dimensional method. The scaler will measure the SED twice, the first measurement being across the shortest diameter and then the second being perpendicular to this (figure 4). This procedure is then followed for the LED. The two measurements are averaged out to produce a single SED or LED that is then used in the 3D equation to estimate a true volume. The individual length of each log is the other important measurement taken.

The data used for this study consists of sample measurements used to check the accuracy of JAS/m^3. Between five and twenty five logs are measured at one time, all consisting of uniform log grades, nominal lengths and species.

4.2. Log scaling (JAS)

As mentioned throughout the literature JAS scaling has been the industry standard for measuring export logs for the last ~35 years. Utilising the 3D measurements as mentioned above, the JAS volume can also be estimated. To do this the values for SED and length are entered into the correct JAS formulae (dependant on length of log).

JAS scaling differs however, as the formula uses rounded down SED values. For example; a log that measures 37cm and 38cm for SED (an average of 37.5cm) would effectively be recorded as 36cm and 38cm respectively. JAS also takes the smaller of the two rounded down SED values for the calculation of JAS volume, so therefore the SED used in the JAS calculation in this example would be 36cm. It is important to calculate the JAS volume of the log using the same measurements in order to get a comparative JAS versus true m^3 volume.

The use of a formula for JAS estimation removes the need for all three key measurements (SED, LED and length) to be used in the equation. This means that the physical measurements are in theory much easier as there is no need to 'match-up' the small and large ends of each log (unlike 3D). When measuring a load of logs it is essential to note that only one log is measured for a length check. This means that not all logs have their own individual length recorded for the use of the JAS calculation.

The difference in the methods for measuring logs using either a JAS scale or a three-dimensional scale alone can lead to some disparity. The rounding down of the SED (JAS) can mean the SED is underestimated, compared to using an average value (3D).

For this study both methods are used and then compared to show the differences observed, table C1 (*Appendix C*) shows the steps involved for each technique, highlighting the differences in measurement methods. For this study the assumption is made that the 3D volume is closer to a true volume as it has more accurate methods of measurement (including the large end diameter instead of using assumed taper) and also uses an average of two SED/LED measurements as opposed to the taking the smaller of the two rounded down values (JAS).

4.3. Data analysis methods

The data analysis to be performed is basic and will primarily be used as preliminary and backing data for the difference prediction method recommended. The initial analysis to be carried out is summary statistics for each data set. The data are characterised using descriptive statistics (minimum, average and maximum values) for each of the variables of interest (small-end diameter, large-end diameter, length and therefore taper of each log).

The taper of the logs will then be analysed and explained using knowledge from previous studies and the distribution of tapers in each study area. Knowledge regarding the tapers that frequently occur throughout New Zealand will be useful in order to predict the expected differences that can occur for any given taper. This data will be presented and analysed in histograms showing distribution, broken down into log grades.

Simple regression models are utilised to establish the trends of difference when taper changes. Comparison between similar and/or the same log grades in the two study areas will be made to see what differences occur. It is important to establish the relationship as one of cause not correlation as taper and difference are not correlated, however taper is a key casual factor for difference in JAS volume estimation, so therefore the relationship is important.

All preliminary analysis is performed in Excel spreadsheets, utilising the correct volume equations and measurement data. Any logs that exhibit excessive differences (i.e. more than three times the 3D volume to JAS volume) will be removed in order to ‘clean’ the data. These values will be identified through the regression analysis that is performed.

The final analysis performed will be in the form of a predictor matrix that uses diameter increments to predict the difference between 3D volume and JAS volume for any log. This difference prediction will be presented in order to provide a means to preview how taper changes the difference of JAS and 3D scale volumes.

5. Data

5.1. Data Sources

Two data sets were used for the analysis of difference caused by taper. The data comes from on wharf measurements performed by the log marshalling companies as commissioned by the log exporters. The measurements are used as a means to check the accuracy of JAS by comparing the JAS volume to the 3D volume. From these measurements conversion factors are updated.

Data were selected to represent the full range of taper that might normally be experience in New Zealand radiata pine plantations. The Southern South Island is thought to be the region where the trees have the most taper, and the East Coast of the North Island, where they have the least taper.

The South Island data is from the Otago region and consists of six years of measurement data from 2012 to 2018. The samples included various log grades and lengths that were measured for reconciliation purposes. The data sets included the key variables for this study; length of log, grade, small end diameter and large end diameter, while also incorporating 3D and JAS formula for the estimation of each respective volume.

The North Island data was extracted from the East Coast North Island region, with measurements occurring over two years, from 2017 to 2018. The measurements for SED, LED and length from this region were entered into the same spreadsheet as the South Island data to ensure that uniform calculations were made.

5.2. Sample Sizes

Table 1 below shows the number of logs measured for each location and log grade. A total of 2,221 logs were measured for SED, LED and length. The smaller sample size for the North Island data set was due to limited historical information and 3D scaling only recently being implemented.

Table 1: *Sample sizes for each respective log grade and location*

	South Island	**North Island**
Pruned Grade	238	50
A Grade	409	400
K Grade	342	N/A
KI	N/A	141
Pulp Grade	524	117
Total	**1,513**	**708**

5.3. Log Grades

Several log grades were recorded in the data, however the five of interest for this study were Pruned grade (a mix of all pruned logs), A grade, K grade, KI grade and Pulp grade. These grades are some of the more common that are exported, with varying size requirements and lengths that are cut. These log grades fulfil the requirements of getting a broad range of export grades to study, while also utilising the literature review findings and including the more common export grades (A grade and K grade)

It is important to note that due to availability of data from the North Island dataset the analysis will be performed on KI grade instead of K grade. The specifications for each log grade (including some aggregated grades) are as follow;

Table 2: *Log Grade Specifications*

	Pruned	A	KI	K	Pulp
SED (minimum)	30cm	30cm	30cm	20cm	10cm
LED (maximum)	N/A	N/A	N/A	N/A	N/A
Lengths (range)	3.7m - 5.1m	3.6m - 5.9m	3.1m - 3.9m	3.6m - 5.1m	3.6m - 3.8m
Branch/Knot Size (max)	0mm	<=120mm	<=200mm	<=120mm	<=200mm
Grade Aggregation	P30, P40	N/A	N/A	N/A	Pulp and downgraded logs

5.4. Taper

To estimate the taper of any given log, the SED, LED and length were used. The equation shown below details how these measurements are utilised in order to get the taper of a log in terms of cm/M.

$$Taper\ of\ a\ \log = \frac{(Large\ End\ Diameter - Small\ End\ Diameter)}{Actual\ Length}$$

Equation 1: *Taper of a log*

The taper equation used is limited however as it only uses two diameter measurements, therefore assuming a uniform taper. This is an issue as a log may exhibit several changes in diameter along any given stem, however for the scope of this study a uniform taper is sufficient due to the 3D volume only being an estimation of true volume.

6. Results

The results section will detail the findings of how taper impacts the estimation difference between a JAS formula and a true m^3 volume estimated using a 3D formula. It is important to note that the JAS formula used is for logs less than 6m in length, therefore the sample excludes logs that are over 6m (when the cut length is 5.9m for example). The impact of using this formula is that a square cross-section is assumed to be the volume of the log. A square cross section is often favourable as when sawing a log, there are often residuals left out due to the cut patterns used.

6.1. Summary Statistics

Two study areas have been observed to get some comparative data, although this is not the focal point of the study. The first study area is the South Island of New Zealand, in particular the Otago region. To be able to predict the difference that is created as a result of taper some basic summary statistics are first explored to find the range of values observed for SED, LED and then length, which when used in conjunction can be used to derive the volume for each log, assuming a uniform taper. The summary statistics for the South Island location can be seen in table 3 below.

Table 3: *Summary Statistics for four key log grades in the South Island*

		Length (m)	SED (cm)	LED (cm)	Taper (cm/m)
Pulp	*Minimum*	3.6	8.5	14.5	0.13
	Average	3.9	21.4	27.1	1.47
	Maximum	4.1	55	64.5	4.89
		Length (m)	**SED (cm)**	**LED (cm)**	**Taper (cm/m)**
K Grade	*Minimum*	3.6	17	20	0.54
	Average	4.2	27.5	35.2	1.87
	Maximum	5.5	58	68	4.89
		Length (m)	**SED (cm)**	**LED (cm)**	**Taper (cm/m)**
A Grade	*Minimum*	3.61	22	31.5	0.54
	Average	4.4	36.4	43.9	1.71
	Maximum	5.99	60	71	3.86
		Length (m)	**SED (cm)**	**LED (cm)**	**Taper (cm/m)**
Pruned	*Minimum*	3.7	31	37.5	0.5
	Average	4.5	44.8	54.8	2.27
	Maximum	5.9	77	94	4.37

As shown on the table above, each of the logs within the data set is grouped in their respective log grades. There are some key points to take from the summary data that can help to explain or provide basis to further analysis. Length of the logs is variable and changes due to cut plans and demand from customers. The impact that length has on the difference comes when differentiating between two logs with the same taper as a longer log will have larger volume, so potentially larger disparities.

The diameter measures of the log are important to highlight as the literature around JAS scaling has said that the JAS scale underestimates the volume for smaller-diameter logs. So the larger the logs, the less they will be affected by JAS scale inaccuracy. Table 2 shows the average SED values for each log grade are much closer to the minimum values than they are to the maximums. The grades have been ordered to show the gradient of size. The LED is less relevant for the effect on JAS (as JAS does not utilise a large-end diameter), but it is important in order to calculate the 3D volume and the assumed taper. Further comparison between the South and North Island examples will be made below.

A comparison between the tapers observed for each log grade is also an important summary statistic that is displayed in tables 3 and 4. Taper is variable within forests for several reasons, so the key information to draw from this basic analysis is where the worst taper occurs between grades and between study sites. Table 3 illustrates that the most average taper is for pruned logs, followed by K, A and Pulp logs. In terms of the worst taper observed however the Pulp and K grades both showed values of up to 4.89cm/m. This taper was from a 4.6m log that had a SED of 30cm and a LED of 52.5cm.

Overall the observed taper for the North Island site (table 4) was less when compared to the South Island, leading to some initial conclusions that the North Island sites consist of larger straighter trees. Overall average taper for the North Island was 1.45 cm/m, whereas the South Island data showed average taper of 1.83 cm/m. The worst performer on average was again the pruned log grade, however the maximum again was Pulp logs. The summary statistics tell us that the worst average taper for both sites occurred with Pruned logs, but the potential for the worst maximum taper occurred in the log grades with smaller minimum SED values such as Pulp and K.

Table 4: *Summary Statistics for four key log grades in the North Island*

		Length (m)	SED (cm)	LED (cm)	Taper (cm/m)
Pulp	*Minimum*	3.9	19	23.0	0.5
	Average	4.5	40.5	46.7	1.4
	Maximum	5.95	101.5	122	4.1
		Length (m)	**SED (cm)**	**LED (cm)**	**Taper (cm/m)**
KI Grade	*Minimum*	3.9	28	31.5	0.3
	Average	3.9	37.2	42.3	1.3
	Maximum	4.0	53.5	62.5	3.3
		Length (m)	**SED (cm)**	**LED (cm)**	**Taper (cm/m)**
A Grade	*Minimum*	3.9	27.5	30.5	0.1
	Average	5.0	38.7	44.4	1.1
	Maximum	5.99	67.0	72.0	3.1
		Length (m)	**SED (cm)**	**LED (cm)**	**Taper (cm/m)**
Pruned	*Minimum*	3.9	28.5	34	0.1
	Average	3.9	40.8	48.5	2.0
	Maximum	4.16	53.0	61.0	4.0

The diameters for the North Island data are larger for three of the four log grades measured, with Pruned logs being the exception. Therefore logs that were measured in the North Island data set will perform better when using a JAS scale. This ideal will be tested further through the regression analysis. The A grade and Pruned logs are comparable for both data sets as the SED and LED measurements are similar. The tapers differ however as mentioned with lower average and maximum values for all log grades.

6.2. Taper Observations

The taper estimation is explored in more detail, with the range of tapers for each log grade quantified to see what expected taper ranges/classes are most common in each region and therefore what differences can be most expected.

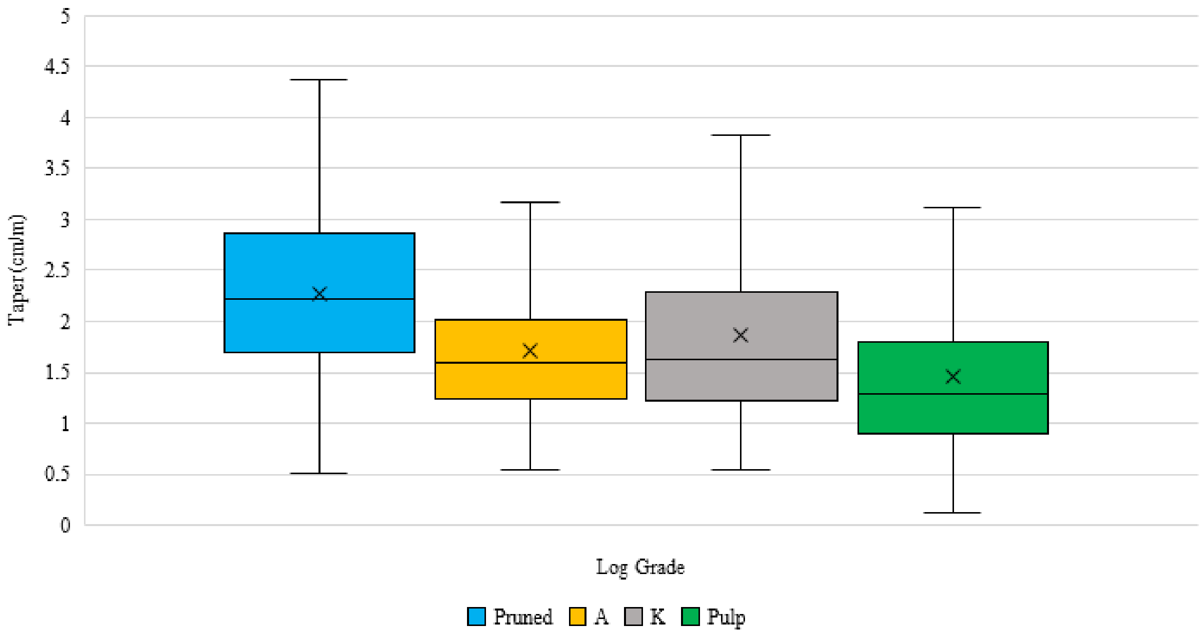

Figure 5: *Boxplots of taper estimations for the South Island dataset*

Boxplots have the ability to quickly show trends in data and make meaningful comparisons between data sets. Figure 5 above shows the boxplots for taper in the South Island. The first point to note is that all log grades show differing distributions, medians and average values. Pruned logs show the largest range and show the highest average taper. A grade and K grade logs have very similar median values, but the range for A grade logs is smaller and the average is lower compared to K grade logs. K grade logs which are seen as poorer quality logs actually showed the lowest average values of taper for the South Island. Overall the South Island data set displays a 5.40E-38 P-Value, so when testing at an alpha value of 0.05 it can be concluded that the tapers observed between each log grade are significantly different.

The taper for the North Island data set is displayed in figure 6 below. Much like the South Island data, pruned logs again show the highest average taper values and also the largest spread. The difference within this log grade suggests that variability of taper is high. A grade logs again show rather exemplary taper estimations, with overall low variation within the log grade and a low average taper value. This is to be expected as A grade logs are seen has high quality and are sold as such (premium log grade). KI and pulp grade logs show similar distributions, at different taper class intervals. The taper for pulp logs in the North Island data set are similar to those in the North Island, but the KI and A grades show less taper. The North Island data set had a P-Value of 9.47E-20. Again this concludes that the dataset shows significant differences between each log grades taper, when testing at an alpha value of 0.05.

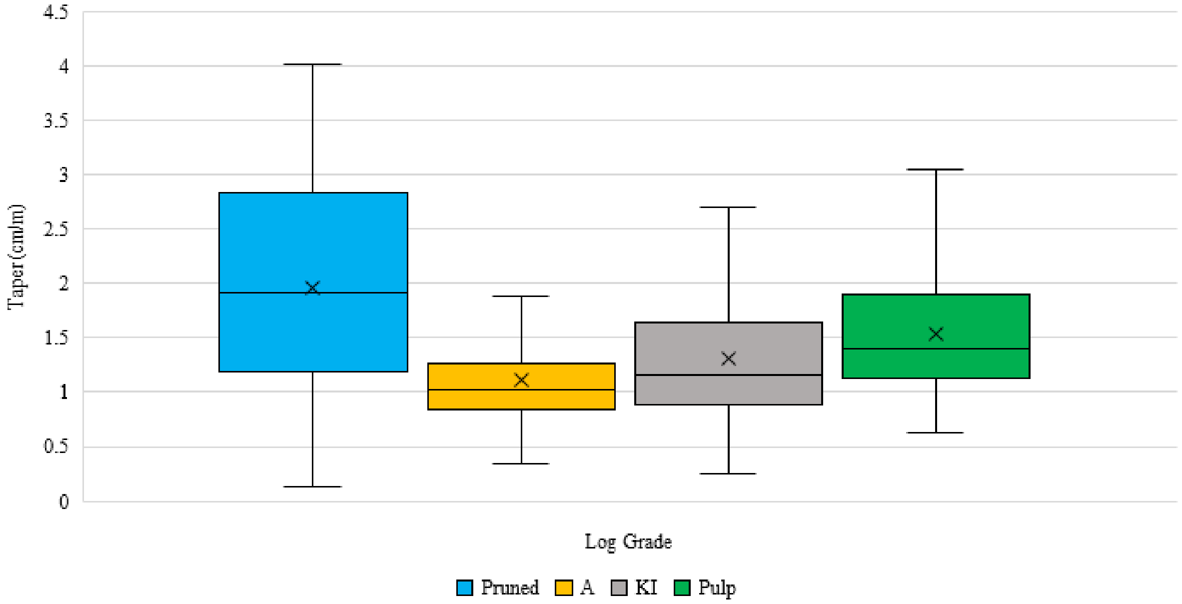

Figure 6: *Boxplot of taper estimations for the North Island dataset*

It is important to note that for both data sets (figures 5 and 6) all log grades have average values that are larger than the median value. This shows that the data has a skew to the lower end of the taper distribution range, this information is further backed up in figures 7 and 8 below; regarding the overall taper distribution. An overall analysis of variation was carried out between the two datasets (North Island and South Island). The P-Value for this ANOVA was 1.65E-28, so there is a significant difference between the tapers observed for the four log grades.

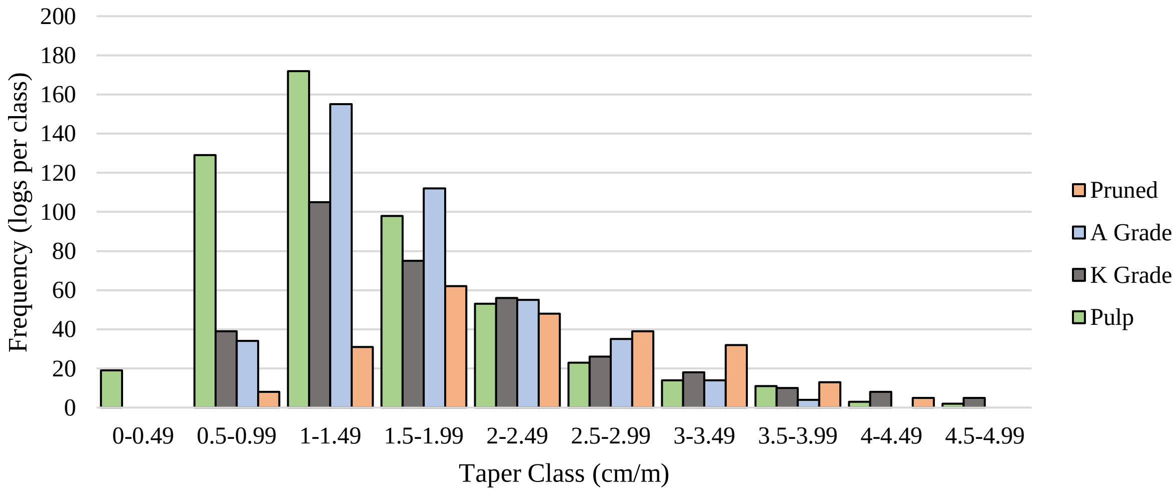

Figure 7: *Taper distribution for all log grades from South Island data set (log grades shown)*

Figure 7 shows the taper distribution for the logs measured from the South Island dataset. The distribution shows a wide range of tapers and has a significant right skew. The South Island data does have a more normal distribution than that of the North Island data (figure 8). The mean value is greater than the median in both examples as there are fewer large tapers that cause the average taper to increase, but do not change where the median value lies. The majority of tapers observed fall between 0.5cm/m and 2.5cm/m. The long tail of this distribution shows the potential for large tapers to occur in this study area. Although there is only a small number of these observations they have the ability to cause large estimation differences. One interesting point to note is that the all logs with the exception of pulp logs have taper of at least 0.5cm/m.

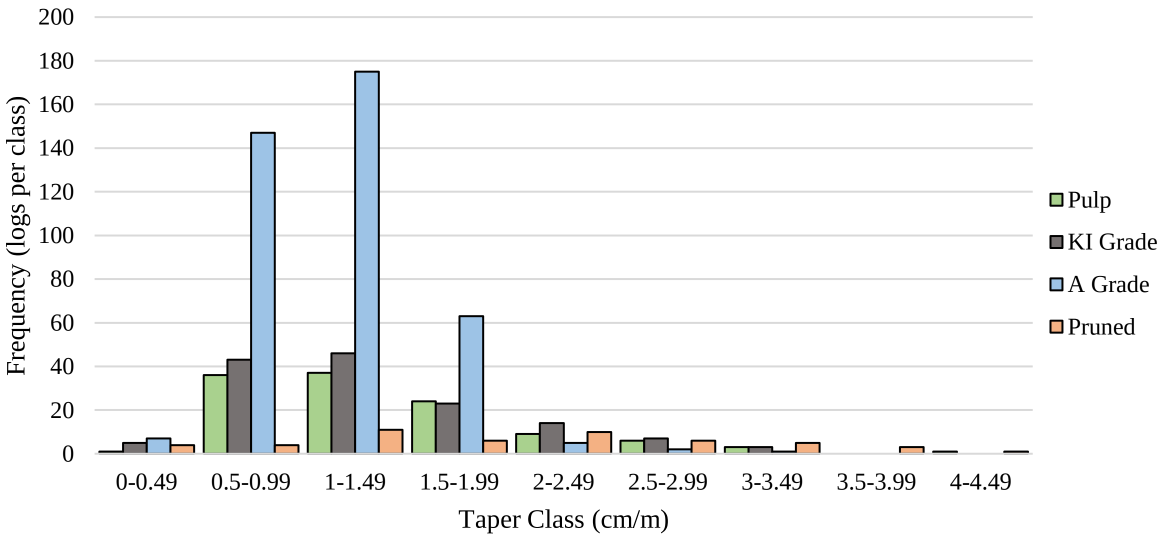

Figure 8: *Taper distribution for all log grades from North Island data set (log grades shown)*

Figure 8 which shows the distribution for the North Island data shows a similar right skew to that of the South Island. The tail is shorter however with the maximum taper only reaching the 4-4.49cm/m class. The high concentration of values in the lower classes (<1.99cm/m) show that taper is not as variable in the North Island data set. The log grades that make up the higher taper classes are pruned and pulp, which coincides with the two worst grades observed in the summary statistics above. There are less logs measured for the North Island data set, however due to the high concentration of low tapers, the average values are assumed to be suitably representative.

The fact that the data sets do not follow a normal distribution is an important factor to consider. In terms of taper, it is most favourable to be as close to 0cm/m as possible. A lot of work and study has gone into growing trees for low taper values, so having a right hand skew in the dataset can be seen as a positive.

6.3. Relationship between taper and estimation difference

To establish if there is any relationship between a change in taper and a change in the difference of JAS volume compared to a 3D (true) volume regression analysis was performed. To remove any issues caused by differing log lengths the differences for these relationships have been presented as percentages of JAS volume. For example a 10% difference means JAS has overestimate the volume of the log by 10%, a negative difference means the log has been underestimated.

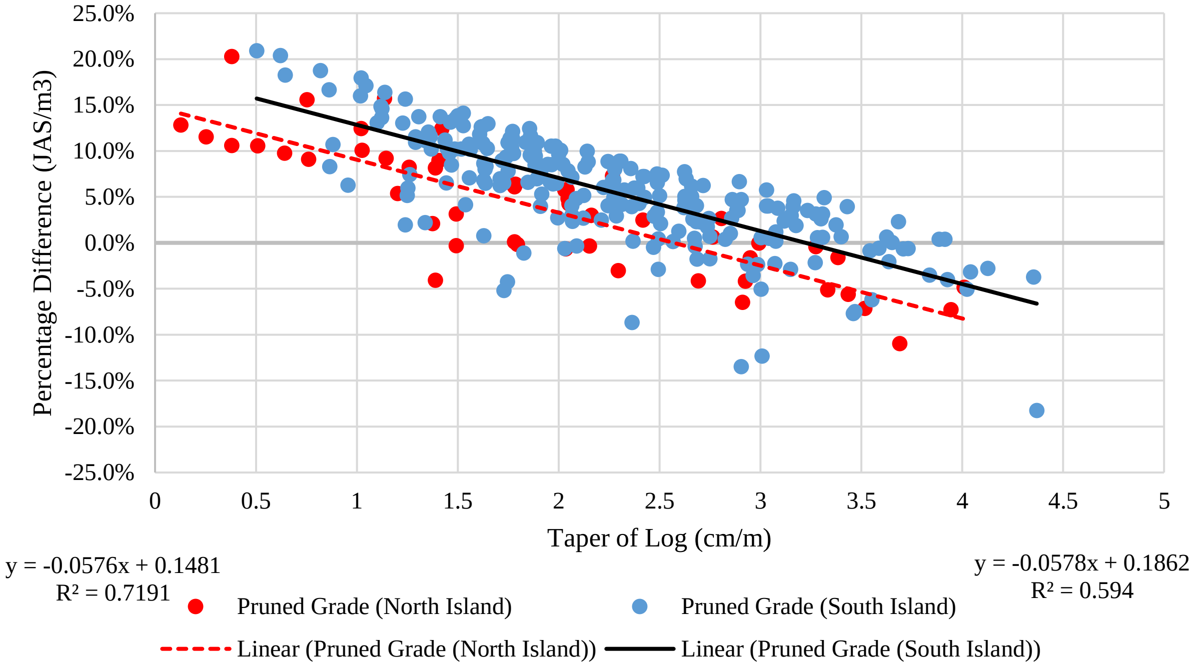

Figure 9: *Pruned Grade logs expected percentage difference of JAS volume to 3D volume*

Each log grade has been separated in order to look at variety based on the minimum SED of each grades specifications. Pruned grade logs have been aggregated to contain a variety of grades including P30 and P40. Figure 9 shows the relationship that is observed for both data sets, in order to see comparisons between taper and percentage difference, but also the difference between the South and North Island data.

The majority of logs are over estimated based on the differences estimated. This means that more volume is being measured and sold than is actually present. The North Island data shows that at approximately 2.5cm/m the trend changes from overestimation to underestimation of difference (based on the linear trend line). For the South Island the trend line passes this threshold at approximately 3.25cm/m, probably due to the number of logs that are underestimated while having small taper. The r^2 values for the North and South Islands are 0.7191 and 0.594 respectively. This explains the fit of the data, with both sets showing strong linear trends.

Figure 10 below shows the same relationship, but looks at A grade logs. The relationship between these datasets is very similar, with a similar cluster of values between 0.5cm/m and 2cm/m, which follows the trends shown in the taper distribution graphs above (figures 7 and 8).

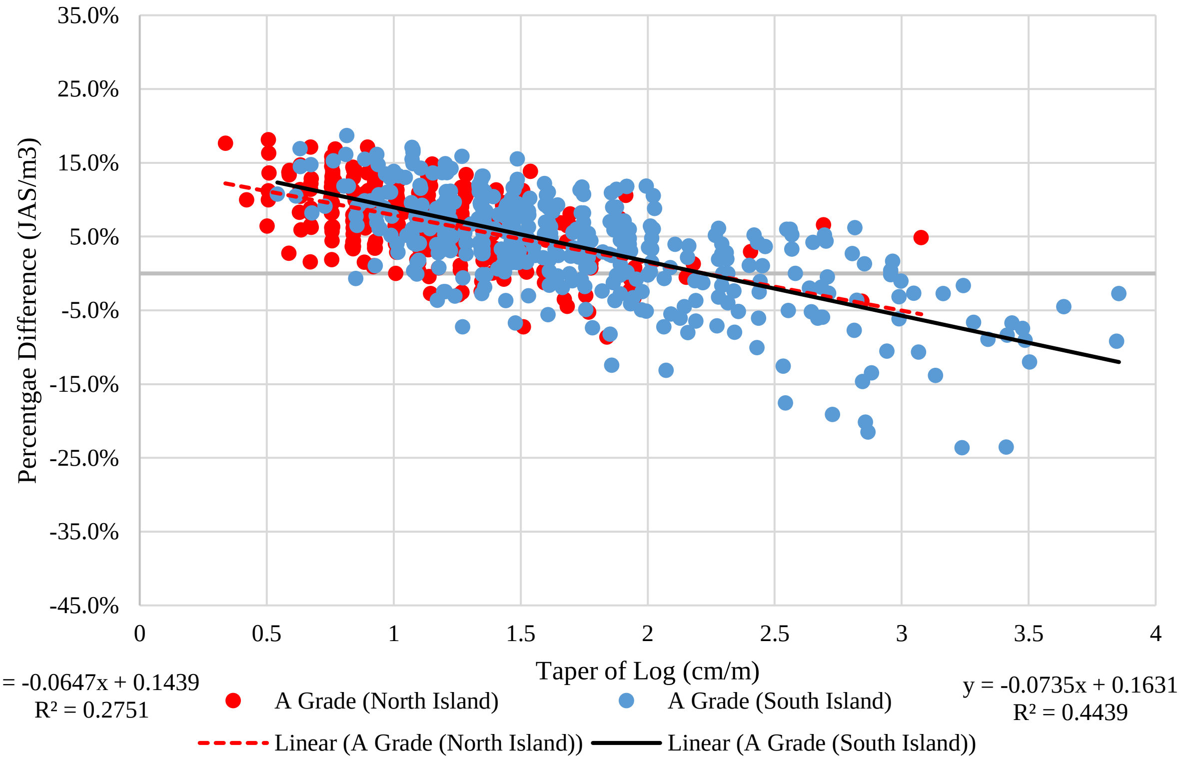

Figure 10: *A Grade logs expected percentage difference of JAS volume to 3D volume*

As shown by figure 10 above, there is a large cluster of A grade logs that have been overestimated (shown by a negative percentage difference). This trend is observed in the taper classes between 0 and 2cm/m. The range of over estimation is between 0% and 15%. A second observation is that at approximately 1.8cm/m of taper the North Island data set trend line crosses and rises above the South Island trend. Very few North Island logs are underestimated by JAS, it is assumed that this is due to the large SED of the logs and the relatively low taper values. The South Island data however has a number of observations that are underestimated. Furthermore, the r^2 values for the North and South Island are 0.2751 and 0.4439 respectively. The data therefore is not as linear as the pruned grade logs, with more noise throughout the data points. This is likely due to the length of the logs varying more dramatically for A grade logs compared to pruned logs. The A grade datasets displayed 10 different cut lengths (between 3.6 and 6m), whereas pruned logs only had 4 different cut lengths (between 3.7 and 5.9m).

A grade logs are seen as the higher quality grade, so it is not surprising that only a handful of the logs are underestimated. If a log is of poor quality (high taper, knot sizes etc.) then it is often downgraded.

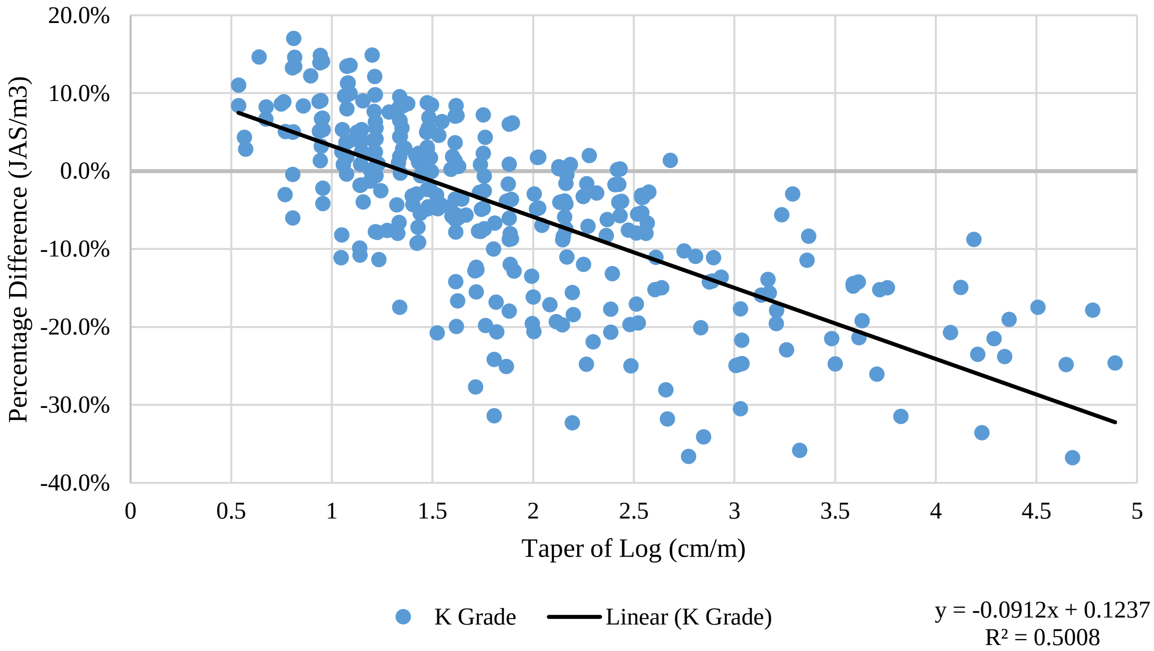

Figure 11: *K Grade logs expected percentage difference of JAS volume to 3D volume*

The next two figures show K and KI grade respectively and separately. Availability of data meant that for the South Island (figure 11), K grade logs were recorded, whereas for the North Island (figure 12), KI grade were available.

The K grade logs observed in the South Island showed large taper ranges from 0.5cm/m to ~5cm/m, with a large cluster between 0.5 and 2.5cm/m. There is a strong linear trend that highlighted a relationship where taper increased the difference of JAS volume to 3D volume also increased. There is still a large cluster of logs that are being overestimated by JAS, however the cluster is more spread and several logs are passing the threshold for K grade logs. When taper is approximately 1.25cm/m the trend line crosses this threshold. The r^2 values for the South Island K grade logs is 0.5008. Cut lengths varied between 3.6 and 5.1m with six individual cut length specifications. These changes could again be accounting for the spread of the data and the relatively low r^2 value.

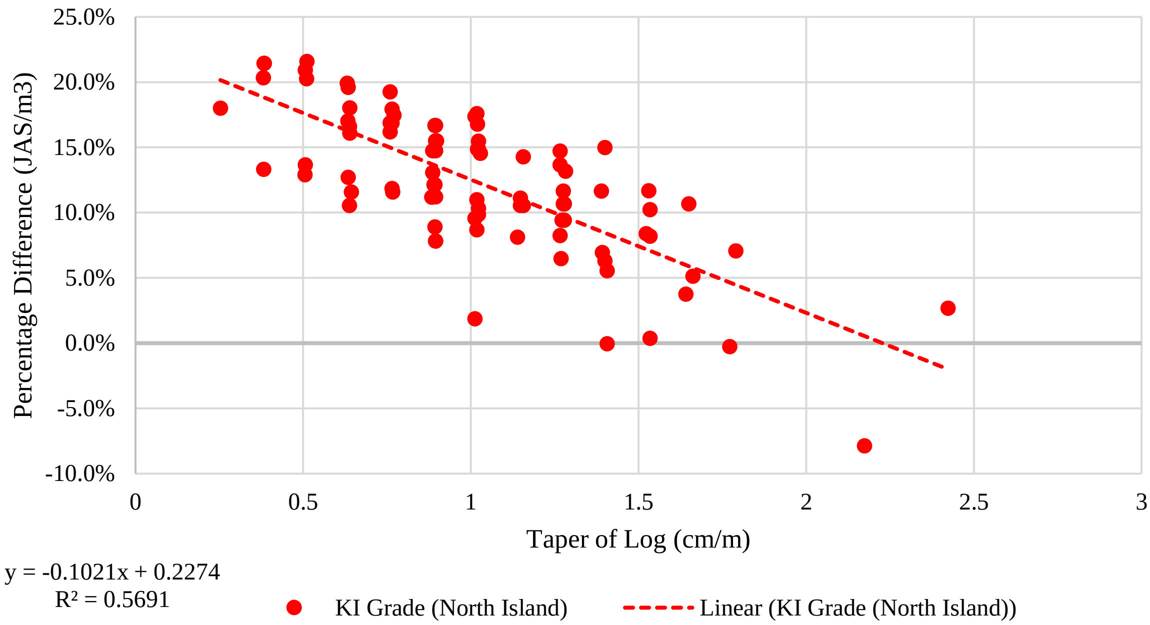

Figure 12: *KI Grade logs expected percentage difference of JAS volume to 3D volume*

The KI grade logs measured in the North island data set had large SED values and small taper. Logs that have these characteristics tend to perform well when measured for volume using JAS scaling. Figure 12 above shows this trend well with only 3 logs measured being over the threshold of estimation difference. The general trend shows that when taper changes, the difference moves closer to where logs are seen to be underestimated. The r^2 value for this series is 0.5691.

Figure 13 below showcases the percentage differences of JAS volume compared to 3D volume for export pulp logs. The South Island dataset which is much more robust contains a range of logs with the majority having small SED values (as small as 8.5cm). This dataset is more consistent of the export pulp grade as the minimum specification is 10cm SED. The North Island data set however is a small sample of large 'downgraded' logs. These logs have SED values in the region of 30cm and therefore perform differently in volume calculations when compared to smaller SED logs.

The two trends observed for each data set are significantly different due to this SED difference.

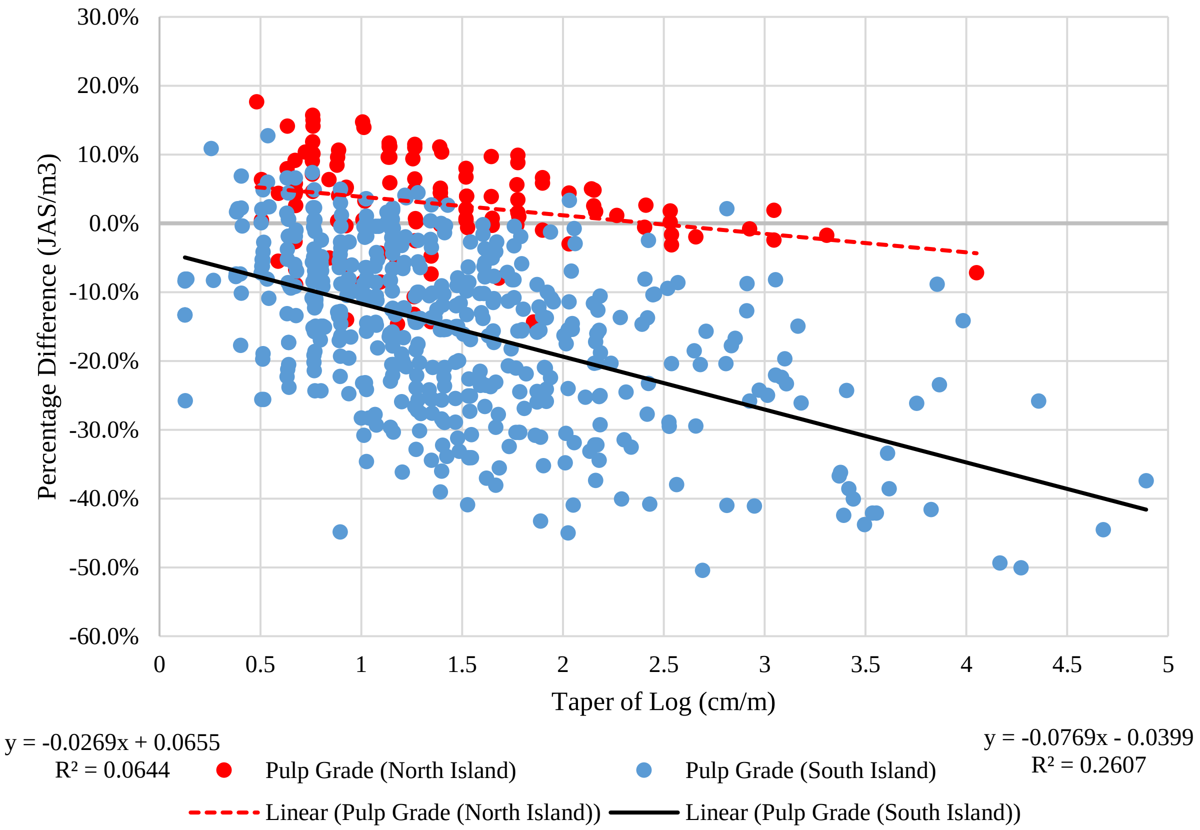

Figure 13: *Pulp Grade logs expected percentage difference of JAS volume to 3D volume*

The South Island data shows that the vast majority of all logs are being underestimated by JAS for the pulp grade. There is a lot of variability within the data set, with tapers reaching close to 5cm/m. There are several logs that display similar taper values, but the percentage difference is different, this is likely due to different actual lengths of the logs as they need to ensure they are over the planned cut length.

The North Island data shows a similar trend to that observed in the KI log grade shown in figure 12. The taper distribution is similar and the SED specification for the KI grade is the same as what these pulp logs were measured at.

Table 5: *Calculated conversion factors and differences for the two data sets*

	SOUTH ISLAND		**NORTH ISLAND**	
	Conversion Factor	**Differences**	**Conversion Factor**	**Differences**
PULP	0.845	-15.8%	1.027	2.7%
K	0.953	-4.7%	-	-
KI	-	-	1.087	8.7%
A	1.037	3.7%	1.064	6.4%
PRUNED	1.055	6.0%	1.035	3.5%

Table 5 above shows the average conversion factors for each log grade in the respective log grades. The average differences are also displayed. The table shows that the two log grades that are negatively affected by JAS scaling are Pulp and K grade logs in the South Island.

6.4. Proposed difference prediction matrix

The prediction matrix uses SED and LED increments at 0.5cm steps respectively. Length can be altered to change the differences estimated. To predict how taper impacts this difference, a base small end diameter was used for each log grade (using the minimum SED specification for each grade: Pulp = 10cm, K = 20cm and A/KI/Pruned = 30cm). The LED was then increased up to 12cm different (i.e. for pulp the last measurement was a SED of 10cm and a LED of 22cm).

The resulting estimation differences have been graphed in order to see a comparison between the log grades and also for a way to be able to predict what the difference may be between a JAS scale volume and a 3D scale volume for any given log dimensions.

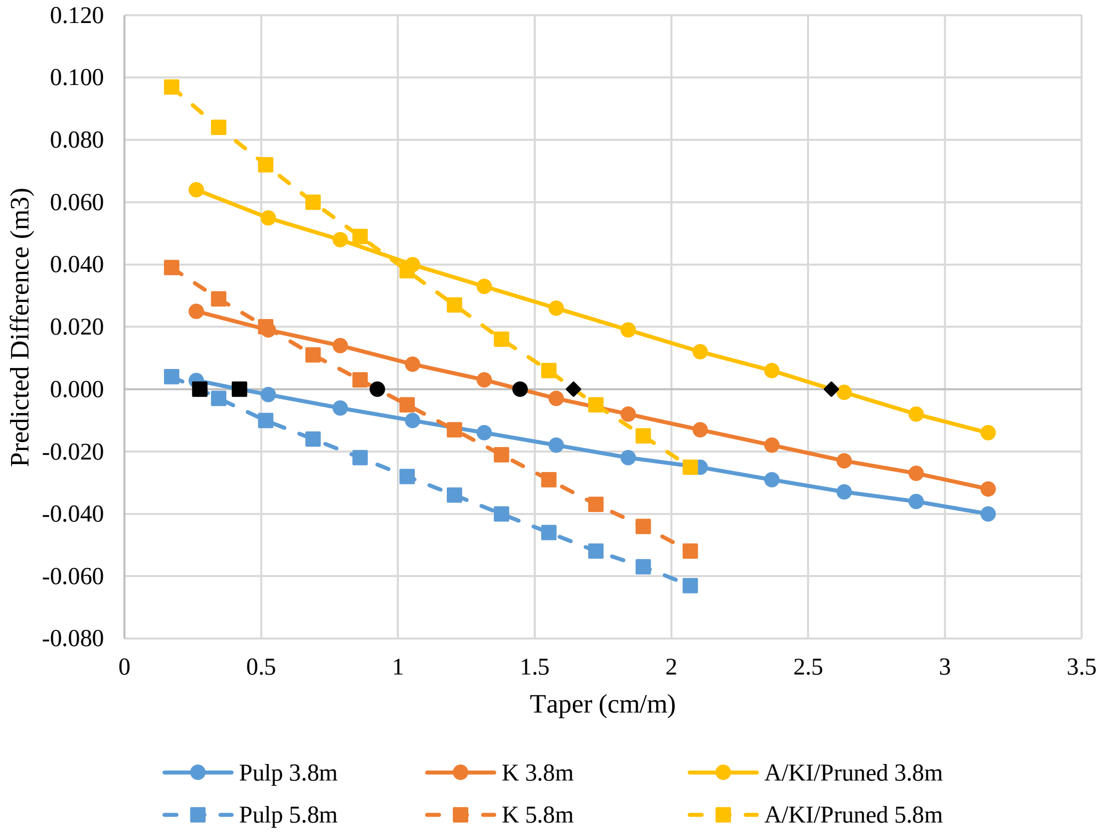

Figure 14: *Predicted difference based on taper of log using smallest SED log grade specification (volume difference)*

Figure 14 shows the predicted difference in the volume measured (m^3) for the three log grade specifications detailed above. It is important to note that this figure is not representative of the entire predictor matrix as it is only based on three SED values. It does however show a dramatized version of the matrix to show potential differences for each individual log measured using JAS and 3D scaling.

The figure shows several pieces of key information that can be utilised in order to predict the difference that is estimated. The first is the difference that is seen between the three log specifications. Logs that have a smaller SED prove to have the largest estimated differences, therefore it is expected that small ‘pulp grade’ logs will be display the largest differences in volume.

The length of the logs also plays a part in the estimated difference between the two measurement methods. This can be seen by the volume differences between the two log lengths used (3.8m and 5.8m). As shown by figure 14 and 15, longer logs are worse in terms of difference.

The taper required for each log specification is also a key piece of information that can be derived from the error matrix. A 5.8m log with a 10cm SED requires 0.276cm/m of taper in order to progress from a state of overestimation, to one of underestimation. For a 3.8m log with the same specification, the required taper increases to 0.421cm/m. The increase of taper is due to having the same SED and LED specifications over a shorter log length, meaning taper increases.

The other two specifications (20cm and 30cm SED values) display similar trends, with longer logs requiring less taper. For K grade, a 5.8m log requires 0.925cm/m of taper, while a 3.8m log requires 1.447cm/m. Finally for A/KI/Pruned grade, 5.8m logs require 1.643cm/m and 3.8m needs 2.586cm/m to be underestimated. This information is useful to be able to predict whether or not the log will be underestimated based on the SED, LED and length of the log.

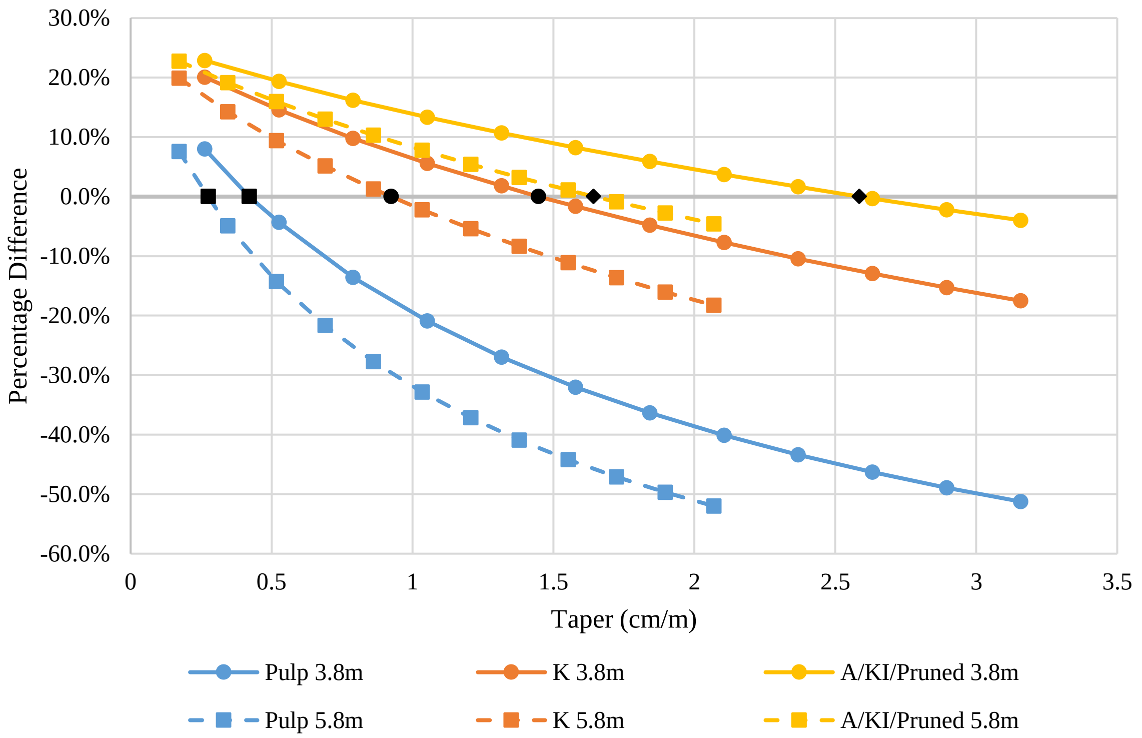

Figure 15: *Predicted difference based on taper of log using smallest SED log grade specification (percentage difference)*

Figure 15 shows a variation of the data presented in figure 14. The percentage differences shown are between the JAS volume estimated and the 3D volume. This allows for more accurate comparisons between the three log grades as it removes any bias based on log size. A log that is large, but shows small differences (such as with A/KI/Pruned) will look a lot closer in terms of volume difference as shown by figure 14. However, this difference is not as large when the relative size of the log is accounted for.

The key conclusion to take away from this adjusted version of the predictor matrix is that pulp logs of any length will be underestimated at a higher rate than K grade logs, furthermore K grade will be worse than A/KI/Pruned. This is based mainly around two variables, SED and length.

7. Discussion

Maximising the value of forests has a high point of emphasis throughout the rotation of a stand of trees. Value comes from a range of activities from planting high quality stock, tending to the stand with appropriate silvicultural methods, all the way through to ensuring harvest costs are minimised etc. So ensuring accurate measurement of logs to maximise the value of exporting them as a commodity product is just as important and should have equal emphasis applied. It is important to note that for this dissertation 3D scaling is assumed to be the true volume.

Comparing the findings of this study to those of previous work is important to see if similar trends are still seen. The conversion factors calculated can give an insight into similarities to a study carried out by Ellis (1996). Table 6 below displays the average conversion factors calculated for the South and North Island data alongside the estimated conversion factors by Ellis (1996).

Table 6: *Comparison of calculated conversion factors to Ellis (1996)*

	South Island	**North Island**	**Ellis 1996**
Pulp	0.845	1.027	0.837
K	0.953	-	0.815
KI	-	1.087	0.901
A	1.037	1.064	0.901
Pruned	1.055	1.035	0.854

The values from the Ellis (1996) study have been extracted from the conversion factors calculated for radiata pine 3-5.9m logs. The average conversion factors are calculated using the average JAS volume divided by the average 3D volume. Selection of the appropriate conversion factors was done by using the average SED and taper values for each log grade. As shown by the table the closest, in terms of conversion factors estimate by this study and Ellis (1996), are pulp logs from the South Island. The logs used in Ellis' study were smaller (SED average of 25.5m and minimum values as small as 4.8cm) when compared the data in this study which could lead to the underestimation of all grades. The larger logs in the North Island Sample (average SED of 39.3cm) could be the reason that all of these logs are overestimated (in terms of the conversion factors above). The South Island Pulp and K grade logs have comparable average SED values to those of Ellis (1996), with Pulp having an average of 21.4cmand K grade having an average of 27.5cm. When comparing the conversions and SED averages, it is apparent that this has an impact on the conversion factor calculated. Logs that have comparable SED averages to Ellis (1996) (South Island Pulp and K grades) have similar conversion factors, however the larger SED grades (South Island A/Pruned and all North Island grades) all display conversion factors over 1. When the conversion factor is over one the JAS volume is larger than the volume calculated using a 3D scale. Through this analysis and comparison it is apparent that small SED values, accompanied by average taper cause underestimation.

The ranges of taper throughout both data sets was important to quantify as base information. The South Island displayed the worst tapers overall, with the worst grade being pruned logs. The North Island in comparison had smaller average taper values, but also displayed pruned logs as having the worst taper. The overall average taper for the entire South Island (all grades) was 1.83cm/m, whereas the North Island data had an average of 1.45cm/m. A variety of site specific reasons can be casual factors for this variation, but due to the scope of this dissertation these are not relevant to explore. The quantification of the taper within New Zealand is the main focal point in order to answer the first research question.

Five key log grades have been analysed, from two locations, in order to get a broad view of the impacts of taper on log measurement estimation differences. Of the five grades pulp was the most disadvantaged when using a JAS formula to estimate the volume. There is a notable difference between the South and North Island data sets, largely due to the difference in SED sizes. The pulp logs from the South Island had small diameters and on average had a SED of 21.4cm. The average volume difference between JAS and 3D for the pulp logs was 21%, meaning that this volume was not being included in the measurement of the logs (underestimating the volume). The North Island data set showed a difference of -2.1%, so these logs were overestimated by JAS scaling. The difference between the data sets is due to the SED measurements of the North Island being much larger, with an average value of 40.5cm.

The K grade for the South Island data set was the only other log grade that was underestimated in terms of the difference between JAS and 3D volumes. This grade had a 6.5% average underestimation, likely due to the small SED average value of 27.5cm.

The underestimation is likely due to the smaller SED specifications that are used for the pulp and K grade logs. The pulp logs in the North Island have been highlighted as an outlier due to their large size and the fact they do not follow the ‘typical’ export pulp log specification. The SED values for all other log grades (Pruned, A, KI and Pulp for the South Island) display SED values of >35cm.

As a result of these estimation differences, several market trends can be seen. Although they are not directly correlated, there could be an element of cause from these observations that drive change in demand from customers. For example, export pulp log prices have been as low as $55 per JAS F.O.B in 2016 (MPI, 2018). The price for these logs currently sits at an average of $140.5 per JAS F.O.B. The increase in price paid could be due to the underestimation of these logs and the offsetting of this difference through correct price setting. The customer may also know the value of the additional timber that is supplied but not measured and therefore be willing to increase the price they pay in order to still secure additional volume.

Similar trends have been seen with the likes of high value pruned logs. These logs, as shown through the analysis, tend to be overestimated, so are sold for high prices to the export market. This impacts the ability of domestic purchases to acquire these logs as the price offered by wealthy overseas buyers is too much to compete with.

The real life data and the predictor matrix both conclude that small SED, longer length (closer to 6m) logs are the ones that are underestimated more frequently, based on the difference between JAS and 3D volumes. The small SED values impact is directly linked to the JAS formula and assuming a rectangular cross section of the log. Therefore when the LED is large compared to the SED underestimation is bound to occur. The logs length has a bearing on the impact of the taper, as shorter logs will display larger tapers when two logs have the same SED and LED measurements.

Overall there are several facets that can impact the estimation differences observed between JAS and 3D scaling volumes. Factors that have not been measured due to the scope of this dissertation include the impact of the rounding differences between JAS and 3D, as JAS rounds down to the nearest even centimetre (appendix B), whereas 3D uses the average of the two SED measurements. The additional cut length of a log also increases the volume of the log superficially, as the customer only pays for a 5.8m log, but may receive a 5.87m length for example.

The export log market works currently as there is a mutual understanding around the qualms that JAS presents. It is well known and familiar now so change is not something that will come around easily, however in terms of accuracy (when compared to an assumed true volume using 3D scaling) it displays some important disparities. It is highly likely that both buyers and sellers are well aware of these differences and can compensate (through price setting) for the incorrect price and volume signals that the JAS scale inaccuracies generate.

8. Conclusions/Recommendations

The principal aim of my dissertation project was to quantify two aspects of the log export industry; taper of the logs in the study area and the impact of this taper on differences in volume as estimated by two scaling methods (JAS and 3D).

The results section details the findings from the data that was analysed and from the estimated differences of JAS and 3D volumes through a predictor matrix. Observations and implications of the results have been highlighted and explained.

The research question are as follow:

1. What are the log tapers that are observed in export logs throughout New Zealand?
2. What is the expected difference observed between JAS volume and true (3D scale) volume per cubic metre volume that is recovered as a result of taper differences?

In terms of answers for these questions, through analysis of the results and discussion, some conclusions have been drawn.

The taper observed throughout New Zealand varied for log grades, lengths and location. Due to the scope of the study the regional differences comparison was removed as a focus, although it is obvious to see some differences between the two study sites. The average taper for the South Island data set was 1.83cm/m, with a range of 0.13cm/m to 4.89cm/m. The North Island data set had average taper of 1.45cm/m, with a range of 0.1cm/m to 4cm/m. From these average values an approximate range of tapers for New Zealand

The expected differences for each log grade and study site have been quantified. Pulp and K grade logs proved to be the worst grades on average in terms of underestimation. The remaining log grades had average estimation differences that showed they were over estimated.

The main focus of this dissertation was to be able to provide a method for log exporters and owners to be able to predict how much volume they will actually be selling when it comes time to harvest. Through a comparison of real life data and the predictor matrix, stakeholders of the forests are able to forecast these differences. The accuracy of the matrix has been checked against the real life data. The estimated differences for each log grade are as follow:

- South Island
  - Pruned Grade = 6.0% (overestimation)
  - A Grade = 3.7% (overestimation)
  - K Grade = -4.7% (underestimation)
  - Pulp Grade = -15.8% (underestimation)
- North Island
  - Pruned Grade = 3.5% (overestimation)
  - A Grade = 6.4% (overestimation)
  - KI Grade = 8.7% (overestimation)
  - Pulp Grade = 2.7% (overestimation)

There will be several situations where these estimations of the difference do not apply. However, by applying the SED, LED and length of any individual log into the predictor matrix, an accurate estimation of the difference will be calculated.

References

Anon. (1967). *Grading and Measuring Regulations for Logs, Japanese Agriculure and Forestry Standards.* Public notice No. 1841, Ministry of Agriculture and Forestry.

Blazier, M. A., Clark, A., Mahon, J. M., Strub, M. R., Daniels, R. F., & Schimleck, L. R. (2013). Impacts of four decades of stand density management treatments on wood properties of loblolly pine. *15th biennial southern silvicultural research conference* (pp. Vol. 175, 29-32). Asheville, NC: US: Department of Agriculture, Forest Service, Southern Research Station.

Duval, A. (2016). *An analysis of vessel loading of export logs at four New Zealand ports.* Christchurch : New Zealand School of Forestry .

Ellis, J. C. (1993). Measurement of roundwood in New Zealand. *N.Z Forestry*, 16-20.

Ellis, J. C. (1994). *Procedures for the measurement of roundwood. Second edition* . Rotorua: NZ Forest Research Institute .

Ellis, J. C. (2005). Measurement of Logs. In M. Colley, *Forestry Handbook* (pp. 150-152). New Zealand Institute of Forestry (Inc.).

Ellis, J. C. (2010). *Comparison between export 2D formula and JAS.*

Ellis, J. C. (2011). A Log Volume Formula for Exporters. *NZ Journal of Forestry*, 20-26.

Ellis, J. C. (2016). Variability in JAS/tonne values. *NZ Journal of Forestry*, 37-43.

Ellis, J. C., & Elliot, D. A. (2001). *Log scaling guide for exporters.* Rotorua: Forest Research Bulletin No. 221.

Ellis, J. C., Sanders, D. H., & Pont, D. (1996). JAS log volume estimates of New Zealand radiata pine and Douglas-fir logs. *N.Z Forestry*, 32-36.

Ellis, J., & Crawley, D. (2014). *Practical log scaling guide.* Tauranga: C3 Publications.

Fernández, M. P., Basauri, J., Madariaga, C., Menéndez-Miguélez, M., Olea, R., & Zubizarreta-Gerendiain, A. (2017). Effects of thinning and pruning on stem and crown characteristics of radiata pine (Pinus radiata D. Don). *iForest-Biogeosciences and Forestry, 10(2),* 383-390.

Fonseca, M. A. (2005). *The measurement of roundwood. Methodologies and conversion ratios.* Geneva, Switzerland: CABI .

Mason, E. G. (2004). *A brief review of the impact of stand density on variables affecting radiata pine stand value.*

MPI. (2017). *Facts and Figures - New Zealand Plantation Forest Industry.* Wellington: Forest Owners Association.

MPI. (2018, September 2018). *Histroic indicative New Zealand radiata pine log prices*. Retrieved from News and Resources: https://www.mpi.govt.nz/news-and-resources/open-data-and-forecasting/forestry/wood-product-markets/historic-indicative-new-zealand-radiata-pine-log-prices/

Nicholls, P. (2017). International Markets - a review. *New Zealand Journal of Forestry*, 16-22.

Punches, J. (2004). *Tree growth, forest management, and their implications for wood quality.*

Appendix A: Formulae for other measurement methods

3D Scale

$$V = \exp\left(1.944157 * \ln(L) + 0.029931 * d_0 - 0.038675 + 0.884711 * \ln\left(\frac{d_1 - d_0}{L}\right)\right) + 0.078540 * {d_0}^2 * L$$

Where:

V = log volume (dm^3)
ln = natural logarithm
exp = antilog of the natural logarithm
L = log length (m)
d_0 = small end diameter (cm)
d_1 = large end diameter (cm)

2D for Export Scale

$$V = \exp(1.944157 * \ln(L) + 0.029931 * (D + 0.995) - 0.038675 + 0.884711 * \ln(2.112 + 0.00071 * (D + 0.995)^2 - 0.0405 * (D + 0.995) - 0.047 * L)) + 0.07854 * (D + 0.995)^2 * L$$

Where:

V = log volume (dm^3)
ln = natural logarithm
exp = antilog of the natural logarithm
L = log length (m)
D = rounded down small-end diameter (cm)

Newton Scale

$$V = 0.01309 * \left({d_0}^2 + 4 * {d_{0.5}}^2 + {d_1}^2\right) * L$$

Where:

V = log volume in cubic decimetres
d_0, $d_{0.5}$, d_1 = diameters under bark at small end, mid-span and large end of log (cm)
L = log length (m)

Huber Scale

$$V = 0.078539816 * D^2 * L$$

Where:

V = log volume (dm^3)
D = diameter at mid-span (cm)
L = log length (m)

Smalian (Sectional Measurement) Scale

$$V = 0.039270 * \sum[({d_0}^2 + {d_1}^2) * (L_1 - L_0)]$$

Where:

V = log volume (dm^3)
d_0, d_1 = diameters under bark at top and base of each individual log section (cm)
L_1, L_2 = log length at top and base of each individual log section (m)

Appendix B: JAS rounding

Table B1: JAS rounding examples

JAS SED	Real measurement range
10cm	10-11.99cm
12cm	12-13.99cm
14cm	14-15.99cm
16cm	16-17.99cm
18cm	18-19.99cm
20cm	20-21.99cm
Cont.	Cont.

Appendix C: Measurement Processes/Differences

Table C1: Two methods of log measurement for export logs (Ellis & Crawley, 2014)

	JAS Scaling	3D Scaling
Step 1	Log truck is weighed and logs are left on the truck	Logs are laid out in small batches (5-25 logs)
Step 2	Length of most accessible log is measured to check ‘cut length’ is larger than the ‘sale length’ (Single log represents entire load	Length of each individual log is measured and recorded
Step 3	Small End Diameter is measured (twice at right angles) with rounding down to the nearest even centimetre	Small End Diameter is measured (twice at right angles)

Step 4	Smaller of the two SED measurements is used, with adjustment factors used when SED measurements are more than 6cm different (2cm will be added to the smallest SED in this case)	Large End Diameter is measured (twice at right angles)
Step 5	Values for smallest SED and length are input into the correct JAS equation (dependent on length of log)	SED and LED are averaged using the two measurements of each respective sawn end
Step 6		SED, LED and Length for each log are input into a 3D formula to estimate the volume

Table C2: Comparison of measurement values of different log measurement methods

	JAS	**3D**	**2D**
SED	Yes – Two measurements, Rounded down to the nearest even centimetre	Yes – Average of the two measurements	Yes- Two measurements, rounding up or down to the nearest even centimetre
MID	No	No	No
LED	No	Y – Average of two measurements	No
LENGTH	Yes – to the nearest 10cm	Yes – to the nearest 10cm	Yes – to the nearest 10cm
TAPER FACTOR	Yes – uses a taper factor for logs over 6m in length No – for logs less than 6m	No – Taper is added to equation through LED/SED difference	Yes- Based on a factor estimated by measurements of 100 logs
	Newton's	**Huber**	**Smalian's**
SED	Yes- average of two measurement at any centimetre increment	No	Yes- Last measurement of increments
MID	Yes – measured using a girth tape	Yes- only uses a mid-girth measurement	Yes- at even length increments between SED and LED
LED	Yes – average of two measurements	No	Yes- First measurement of increments
LENGTH	Yes – to the nearest 10cm	Yes – to the nearest 10cm	Yes – to the nearest 10cm
TAPER FACTOR	No	No	No- Estimated using increment changes